Contract No. NAS 9-18395
Mod. 10
DRD No. MA-1292T

LITHIUM D CELL STUDY

FINAL REPORT
CONTRACT NO. NAS 9-18395

P. Size, E. Takeuchi

Submitted to

National Aeronautics and Space Administration
Lyndon B. Johnson Space Center

31 MARCH 1993

Wilson Greatbatch Limited
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ABSTRACT

The purpose of this contract is to evaluate parametrically the effects of various factors including the electrolyte type, electrolyte concentration, depolarizer type and cell configuration on lithium cell electrical performance and safety. This effort shall allow for the selection and optimization of cell design for future NASA applications while maintaining close ties with WGL's continuous improvements in manufacturing processes and lithium cell design.

Taguchi experimental design techniques are employed in this task, and allow for a maximum amount of information to be obtained while requiring significantly less cells than if a full factorial design were employed.

Acceptance testing for this task is modeled after the NASA Document EP5-83-025, Revision C, for cell weights, OCV's and load voltages.

The performance attributes that are studied in this effort are fresh capacity and start-up characteristics evaluated at two rates and two temperatures, shelf-life characteristics including start-up and capacity retention, and iterative microcalorimetry measurements. Abuse testing includes forced over discharge at two rates with and without diode protection, temperature tolerance testing, and shorting tests at three rates with the measurement of heat generated during shorting conditions.

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1.0 INTRODUCTION

As an addition to the Li-BCX battery development program (contract no. NAS 9-18395) this effort was undertaken to evaluate parametrically the effect of various design factors on electrical performance and safety characteristics of the spiral wound D cell. The objective of this modification of the program is to allow for the selection and optimization of the various factors which meet the performance and safety criteria for future space applications, while allowing for a close relationship with WGL as we grow with continuous improvements to manufacturing and cell design.

There are four tasks involved in this effort, which are manufacturing of spiral wound D cells, acceptance testing, electrical performance testing, and abuse testing.

In task 1, 540 spiral wound lithium D cells were fabricated with 18 unique cell designs, or identities. The 18 configurations resulted from the utilization of an L18 experimental design as part of the Taguchi approach. The 18 cell configurations were unique designs in that they varied with respect to electrolyte type, electrolyte concentration, depolarizer type, and mechanical cell design.

In task 2, acceptance testing was performed with respect to cell weight, OCV and load voltages. Since there were 18 configurations being evaluated, the acceptance testing was done to establish acceptable values for each of the three parameters for the 18 different configurations, rather than a pass/fail criterion.

Task 3 involved electrical performance testing which included fresh capacity and start up characteristics at two rates and two temperatures, shelf-life characteristics determined by actual discharge performance as well as iterative microcalorimetry measurements, and temperature tolerance testing.

Task 4, which focused on abuse testing involved forced over discharge at two rates both with and without by-pass diodes, and variable rate short circuit tests where the total heat output was measured during these abusive conditions.

This work was funded under Contract 9-18395, modification 10, administered by the Johnson Space Flight Center under the direction of Mr. B. J. Bragg.

2.0 EXPERIMENTAL METHOD

The Taguchi Method of Experimental Design was utilized as the basis for this contract [T.B. Barker, Engineering Quality by Design, Marcel Dekker, Inc., 1990]. This state-of-the-art methodology allows for examination of many variables at one time through the use of fractional factorials, as opposed to classical experimental design methods which utilize one factor at a time techniques, or full factorials. Taguchi methodology was first introduced to the United States by Dr. Genichi Taguchi in 1980 when AT&T brought him from Japan to assist in their Quality Assurance Laboratories. Since then, the Taguchi philosophy has been a widely accepted discipline in the U.S.

One of the first premises of the Taguchi approach is to maximize the amount of information available while minimizing the total number of experimental combinations required to gain that information. The number of experimental combinations (N) required in classical experimental designs utilizing full factorial matrices can be calculated by taking the number of levels for each factor (L) and raising it to a power equal to the number of factors (f) in the experiment. For example, an experiment which evaluated four factors at three levels would require L^f or 81 experimental combinations to cover all possibilities. Taguchi experimental designs which are based on fractional factorials, or orthogonal arrays, utilize a fraction of the experimental combinations to obtain detailed information about the effects of the factors on the output of interest. Depending on the type of experiment and the required information, use of Taguchi experimental designs would require either 18 or 27 experimental combinations to cover the same ground that the classical experiment would have for this example. The selection of the proper orthogonal array requires knowledge of the the Taguchi method and is determined by the type of information required as well as the possibility of interactions between any two given factors. This also requires prior knowledge of the technology being investigated.

For this effort, an L18 experimental design was chosen for three reasons. First of all we were interested in evaluating three factors at three levels, and one factor at two levels. This design nicely accommodated this type of experiment. Additionally, the L18 matrix is designed specifically to diffuse any interactions between factors evenly across the orthogonal array. Since we believed that the possibility of interactions was small, there should be no confounding of interactions with main effects. Finally, the L18 is cost effective and resulted in a 33% reduction in the amount of cells required if an L27 were utilized instead. Classical full factorial experiments would require 54 experimental combinations, three times as many cells as the L18 design.

The four factors studied in this effort were electrolyte type, mechanical cell design, depolarizer type and electrolyte concentration.

There are two commonly used electrolyte salts in lithium oxyhalide cell technology, that were evaluated in this study. They are $LiAlCl_4$ (LAC) and $LiGaCl_4$ (LGC). Both of these electrolyte salts are utilized in commercial spiral wound cells fabricated by WGL.

WGL has also developed three different D cell designs which were investigated in this study. They are the NASA BCX 149 D cell (part #3B1910-XA), the Universal D BCX 72 D cell (part # 3B0075-ST), and the JPL thionyl chloride D cell (part # 6P1204-ST). The NASA D cell is a space qualified D cell which has an effective working electrode surface area of 123 cm^2 and is designed for hand wound assembly. This is a low to moderate power design and has been demonstrated to be temperature tolerant at OCV up to 149°C. The Universal D cell represents current manufacturing practices of WGL and is a machine wound, moderate to high power cell, which exceeds average capacities of 15 Ah. This design has a working electrode surface area of 247 cm^2 and has been demonstrated to be temperature tolerant to 72°C. The JPL D cell was designed and built by R&D under the Jet Propulsion Laboratory Contract #958449. It is a very high power cell which was designed for hand wound assembly, and its temperature tolerance has not been demonstrated. These three designs represent the three levels of cell design and are representative of the Li-oxyhalide wound elements available for space qualification.

The electrolyte salt concentration, which affects conductivity in the catholyte as well as electrical performance characteristics, was evaluated at three levels - 0.6M, 1.2M and 1.8M.

Three different oxyhalide depolarizers were investigated in this study. They are TC (thionyl chloride), BCX (BrCl in thionyl chloride) and CSC (chlorinated sulfuryl chloride).

These four factors were evaluated using an L18 orthogonal array, which accommodates analysis of the main effects of these factors on the various performance attributes. Figure 1 shows that this array can accommodate up to eight factors, seven of which are at three levels, and one factor is investigated at 2 levels. For this experiment we place the electrolyte type in column 1, since it is a two level factor. The remaining three factors are placed in columns 2, 3, and 4 (see figure 2).

row/column->	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
1	1	1	1	1	1	1	1	1
2	1	1	2	2	2	2	2	2
3	1	1	3	3	3	3	3	3
4	1	2	1	1	2	2	3	3
5	1	2	2	2	3	3	1	1
6	1	2	3	3	1	1	2	2
7	1	3	1	2	1	3	2	3
8	1	3	2	3	2	1	3	1
9	1	3	3	1	3	2	1	2
10	2	1	1	3	3	2	2	1
11	2	1	2	1	1	3	3	2
12	2	1	3	2	2	1	1	3
13	2	2	1	2	3	1	3	2
14	2	2	2	3	1	2	1	3
15	2	2	3	1	2	3	2	1
16	2	3	1	3	2	3	1	2
17	2	3	2	1	3	1	2	3
18	2	3	3	2	1	2	3	1

Figure 1 L18 orthogonal array.

Since only the first 4 columns are utilized in this experiment, the experimental matrix is simplified.

Identity#/Factor->	electrolyte	D cell design	depolarizer	electrolyte concentration
1	LAC	NASA	BCX	0.6M
2	LAC	NASA	TC	1.2M
3	LAC	NASA	CSC	1.8M
4	LAC	UNIV	BCX	0.6M
5	LAC	UNIV	TC	1.2M
6	LAC	UNIV	CSC	1.8M
7	LAC	JPL	BCX	1.2M
8	LAC	JPL	TC	1.8M
9	LAC	JPL	CSC	0.6M
10	LGC	NASA	BCX	1.8M
11	LGC	NASA	TC	0.6M
12	LGC	NASA	CSC	1.2M
13	LGC	UNIV	BCX	1.2M
14	LGC	UNIV	TC	1.8M
15	LGC	UNIV	CSC	0.6M
16	LGC	JPL	BCX	1.8M
17	LGC	JPL	TC	0.6M
18	LGC	JPL	CSC	1.2M

Figure 2 Experimental matrix.

For each test condition, three iterations of the experimental matrix were manufactured and tested, with the exception of the short circuit testing which utilized one iteration. The results of each of the tests were then analyzed by using Lab Partner software. Analysis of variance (ANOVA) was conducted and the main effects of the factors were determined and graphed for each factor as it played a role in the outcome of the testing. This type of analysis allowed for the determination of the proper settings of each factor for each performance or safety attribute.

3.0 CELL MANUFACTURE

Five hundred and forty D cells were assembled in a laboratory setting for prototype test purposes. Since modified versions of current D cell designs were fabricated, full engineering packages for the eighteen configurations were not available. However, R&D standards for build documentation were employed which describe the design of the cell, the start date and the completion date (fill date) of the build, and the name of the build technician(s). The weights of the anode, cathode, and catholyte were also documented.

Wherever possible, lot commonality was maintained for the cathode, anode and electrolyte materials. One exception is the electrode materials for the NASA D cells, which required refabrication and subsequently new lots of lithium and carbon. However, lot commonality was maintained within the group of NASA D cells, and total lot commonality was maintained for the catholyte in all cells.

All cells were manufactured with 0.093" headers and H&V separator material as per the statement of work paragraph 3.0. While the statement of work also called out that the cells be machine wound, this was only possible for the Universal design and the JPL design. The Universal cell was designed specifically for machine winding and therefore represented the most easily manufactured design. The JPL design, which was engineered for hand winding, was modified to accommodate machine winding. The NASA cell was designed for hand wound assembly. These cells were built with the original intent of machine winding. However, due to the thickness of the electrodes in the assembly, this design could not be machine wound without risking violation of the separator. In order to accommodate machine winding, the NASA D cell would need to be totally redesigned. Since any data generated on the basis of this design would not be comparable to previously generated data on the NASA D cell, it was mutually agreed that for the purpose of this contract the NASA D cell would be hand wound. For this reason it was necessary to rebuild 180 cells.

Since there were eighteen different cell configurations in this study, with three depolarizers, three designs, two electrolytes and three electrolyte concentrations, the fill weight of each of the cells was determined such that all cells were temperature tolerant to 149°C.

A total of 89 D cells were delivered to Johnson Space Center at the completion of the contract.

4.0 ACCEPTANCE TESTING

Acceptance testing was performed on the cells patterned after the ATP tests of NASA document EP5-83-025 for weights, open circuit voltages and load voltages. Five hundred twenty six cells were exposed to 160°F and tested for weight and OCV. Eighteen of each configuration were load tested, since not all cells were finished appropriately for ascertaining load voltages. Only those cells designated for discharge and microcalorimetry were easily adapted for the load check. Other cells in the study were configured without fuses or solder tabs. A total of 324 cells were load checked. The load used for the acceptance testing was determined for each of the three basic cell designs such that each design was tested at approximately the same current density as dictated by NASA document EP5-83-025. All acceptance data was packaged along with the 89 cells delivered to Johnson Space Center. Appendix A includes the NASA JSC Document EP5-83-025 Rev. E.

5.0 PERFORMANCE TESTING

Capacity and start up performance was characterized for fresh cells at rates of 1A and 3A and at temperatures of 25°C and -25°C. After 1 year storage at room temperature, the 25°C discharge test was repeated at both rates and capacity retention information was calculated. Cell capacities were determined to a cut-off voltage of 2.0V and start up characteristics were evaluated at 1,5 and 60 seconds. The running voltage was also evaluated at 50% depth of discharge. All cells were discharged under constant current conditions using a MACCOR Model 3 test measurement system , and the temperature of each cell was monitored by individual thermocouples.

Microcalorimetry measurements were obtained at room temperature and OCV four times during the course of one year, and the self-discharge currents for each of the 18 configurations were calculated. While microcalorimetry provides an approximation of the rate of energy loss in cells over time, the actual degredation of cell performance may vary from microcalorimetry predictions. However, general trends in self-discharge rates can be accurately predicted by microcalorimetry. The effects of the four factors on self-discharge rates were analyzed by ANOVA and represented graphically.

Temperature tolerance information was obtained for all configurations at 0% and 100% depth of discharge. Cells were initially exposed to 139°C for 15 minutes and observed for changes in cell containment. The temperature was raised by 10°C and the process repeated up to 159°C.

5.1 FRESH 1A ROOM TEMPERATURE PERFORMANCE

Under room temperature (25°C) and 1A conditions, the start up characteristics were determined for each of the 18 configurations and the effect of each of the factors on start up was analyzed. The ANOVA analysis for each of the three reference points in the start up portion of the test indicates the relative importance of each of the factors in the experiment. Initially, the start up characteristics of the cells are mostly affected by the electrolyte salt and the depolarizer type. Figure 3 illustrates that the LGC electrolyte salt is favored over the LAC salt for the initial start up of the cells, where the voltage at 1 second is at 3.44V for cells with LGC electrolyte vs. 2.91V for cells with LAC electrolyte, and the type of salt used contributes 26.7% to the overall variation in the initial voltage. After 5 seconds this contribution drops to 20.6%, with LGC electrolyte remaining the favored electrolyte type. After 60 seconds most of the cells have recovered to their running voltage and there is little difference between the two electrolytes. Figure 4 illustrates the effect of the depolarizer type on cell start up, and it is clear that the BCX depolarizer offers the best start up performance of the three depolarizers studied. Initially the depolarizer contributes 35.2% to the variation in start up voltages. However, after 60 seconds on test, the depolarizer plays an even stronger role, contributing 94% to the variation in voltage. Figures 5 & 6 illustrate the effect of the cell design and the electrolyte concentration on the start up characteristics of D cells. These two factors had little effect on the start up performance of D cells under these conditions. The cell design contributed from 1.7 - 1.9% to the variation in performance and the electrolyte type contribute from 0.6 - 6.6% of the variation.

The running voltage at 50% DOD was mostly affected by the cell design and the depolarizer type. Figures 7 & 8 illustrate their effects. The cell design contributed 42.3% and the depolarizer contributed 22.2% to the variation in running voltage. The JPL design offered the highest running voltage (3.35V) as did the BCX depolarizer (3.31V).

The delivered capacity of D cells under this set of conditions was mostly affected by the electrolyte type and the depolarizer type. The electrolyte type contributed 13.1% and the depolarizer type contributed 41.5% to the variation in 2.0V capacity. The main effects of the electrolyte type favors the LGC electrolyte, where

Figure 3

Effect of electrolyte salt on voltage delay of D cells discharged at 1A under room temperature conditions.

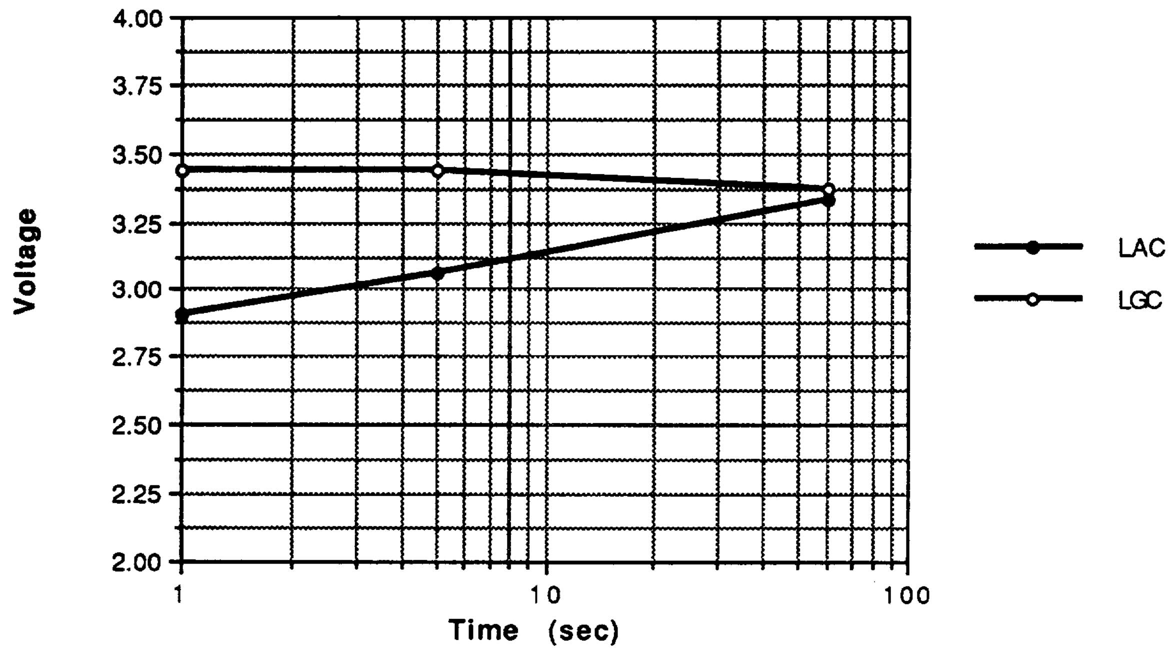


Figure 4

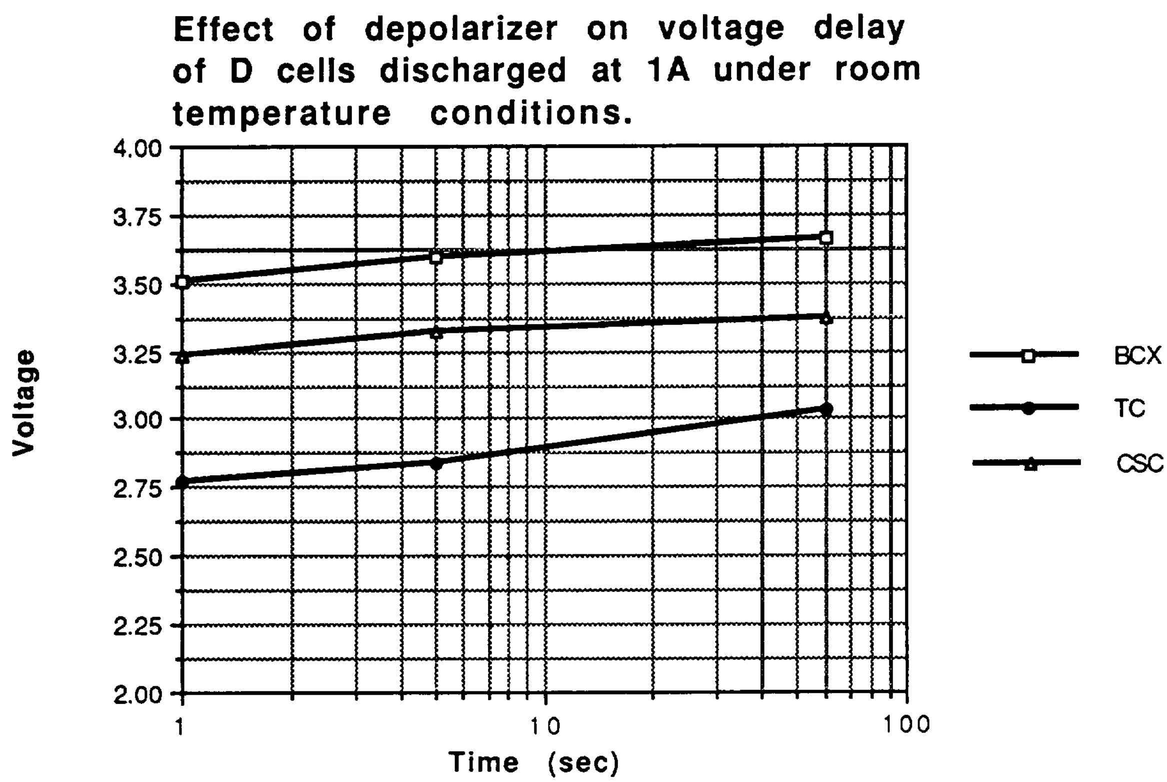

Effect of depolarizer on voltage delay of D cells discharged at 1A under room temperature conditions.
Voltage
4.00
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
1
10
100
Time (sec)
BCX
TC
CSC

Figure 5

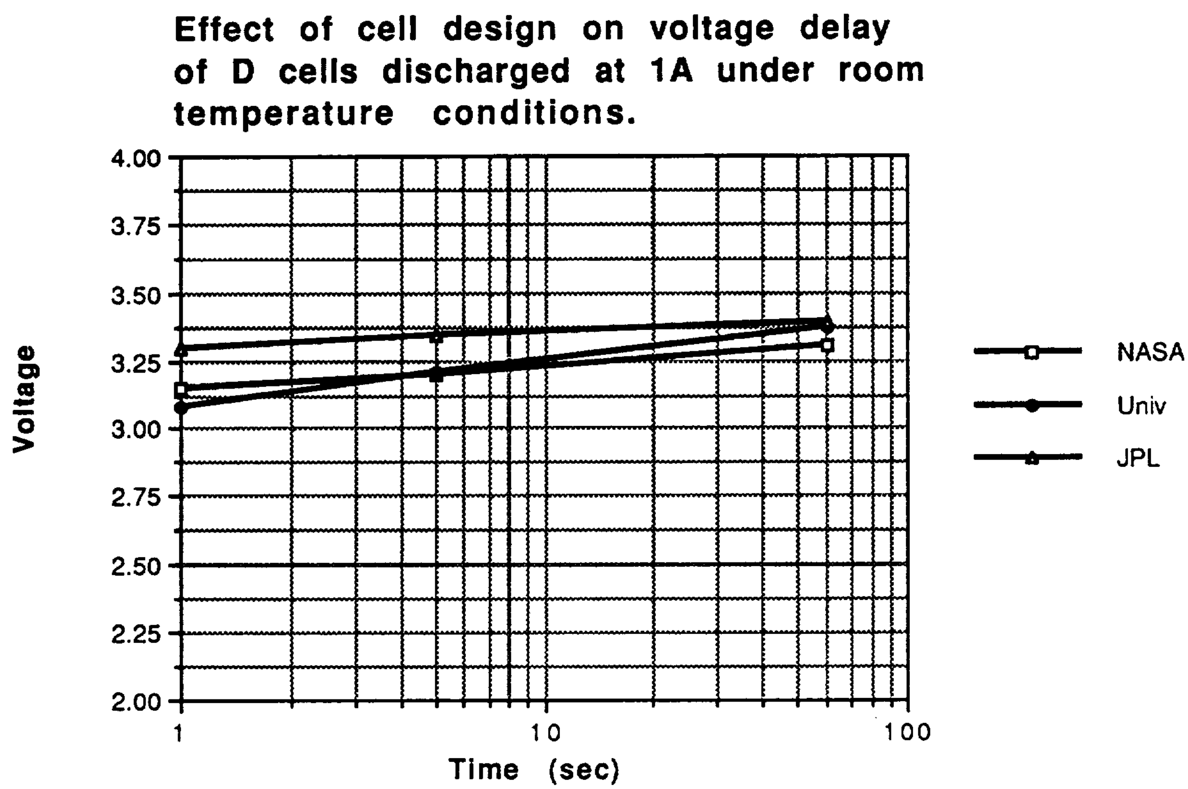

Effect of cell design on voltage delay of D cells discharged at 1A under room temperature conditions.
4.00
3.75
3.50
3.25
3.00
2.75
2.50
2.25
2.00
Voltage
1
10
100
Time (sec)
NASA
Univ
JPL

Figure 6

Effect of electrolyte concentration on voltage delay of D cells discharged at 1A under room temperature conditions.

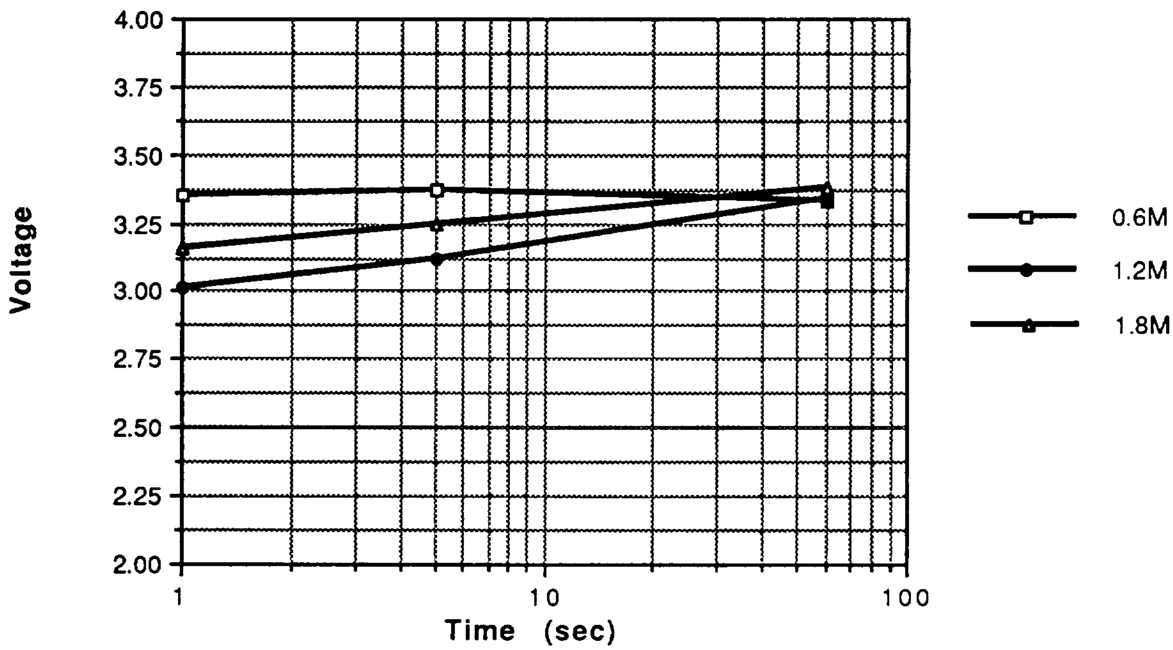


Figure 7

Effect of cell design on running voltage of cells discharged at 1A under room temperature conditions.

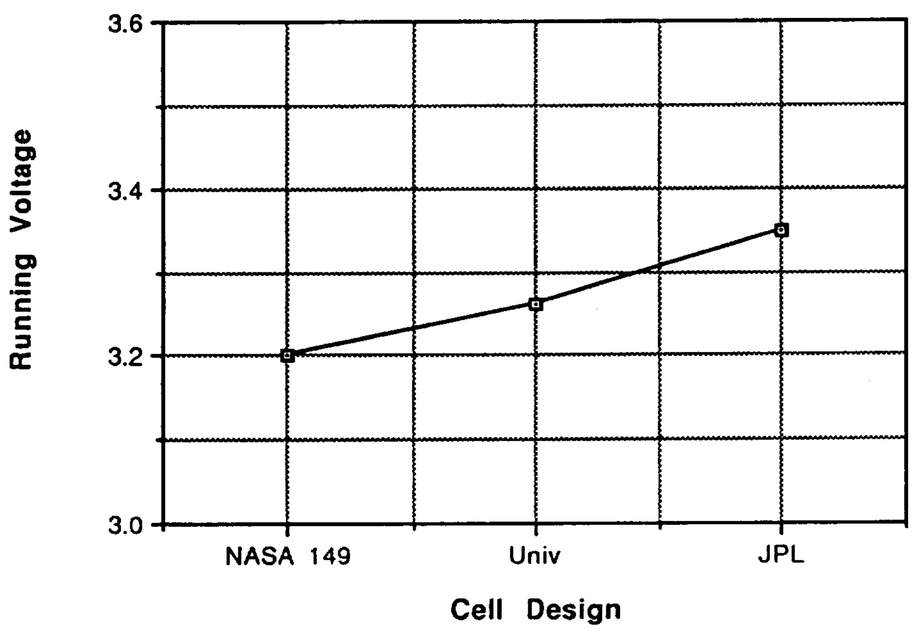
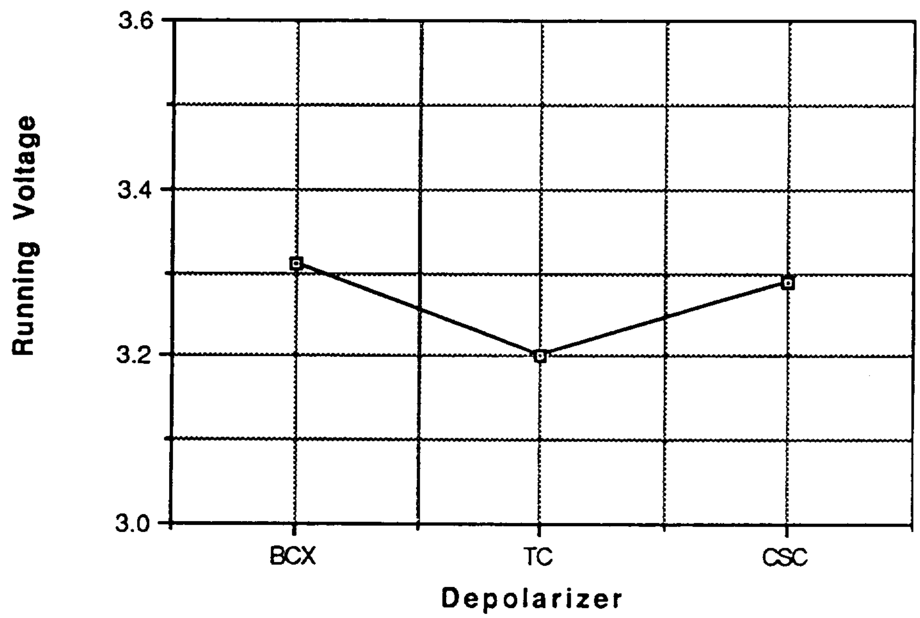


Figure 8

Effect of depolarizer on running voltage of cells discharged at 1A under room temperature conditions.



cells containing this electrolyte delivered 10.6 Ah to 2.0V compared to 8.8 Ah for cells with LAC electrolyte. (See Figure 9). Figure 10 illustrates the effect of the depolarizer type on delivered capacity. Cells with CSC depolarizer delivered average capacities of 11.9 Ah compared to 8.8 Ah for cells with BCX and 8.3 Ah for cells with TC depolarizer. Figures 11 - 28 are representative discharge curves for each of the 18 configurations tested. The ANOVA reports for each of the 5 measured responses are included in Appendix B.

5.2 FRESH 1A, -25°C PERFORMANCE

Under 1A, -25°C conditions, the initial voltage delay of fresh cells was affected by the electrolyte salt, the cell design, and the electrolyte concentration. Again the LGC electrolyte resulted in better start up characteristics than the LAC electrolyte. Contributing 18.8% to the variation in performance, the LGC electrolyte produced start up voltages of 3.06V and the LAC electrolyte had start up voltages of 2.22V. The gap widened after 5 seconds and cells with LGC electrolyte reached voltages of 3.14V and cells with LAC electrolyte dropped to 1.68V. After 60 seconds on test, LGC is still favored over LAC electrolyte, but the overall contribution of electrolyte to performance drops to 10.4%. Figure 29 illustrates the effect of electrolyte type on start up characteristics. Figure 30 illustrates the effect of the cell design on start up of D cells. Initially the cell design contributes 21.6% to the variation in performance and the JPL and UNIV designs have similar starting voltages. By the end of the 60 second test, the % contribution drops to 4.6%, with the UNIV design performing somewhat better than the other two designs. Figure 31 illustrates the effect of the depolarizer on start up performance and the BCX electrolyte outperforms the other two depolarizers. However, the % contribution of the depolarizer is small (≈6%). This holds true for the duration of the test. Figure 32 shows that the electrolyte concentration plays a role in start up performance under these conditions. The lower molarity electrolyte provides better start up voltages than the higher molarity electrolytes. It should be noted that many of the cells had difficulty starting up and/or maintaining their running voltages under this set of test conditions.

The running voltage at 50% DOD was not greatly affected by any of the factors tested, and the error in the experiment was 81%. When the variation in performance is affected by outside noises to such an extent, it is difficult to assess the importance of the controlled factors in the experiment.

The delivered capacity to 2.0V is affected the most by the electrolyte type and the cell design. However, it is important to stress that the outside noises in this experiment were the largest contributors, accounting for 72% of the variation. Figures 33 -

Figure 9

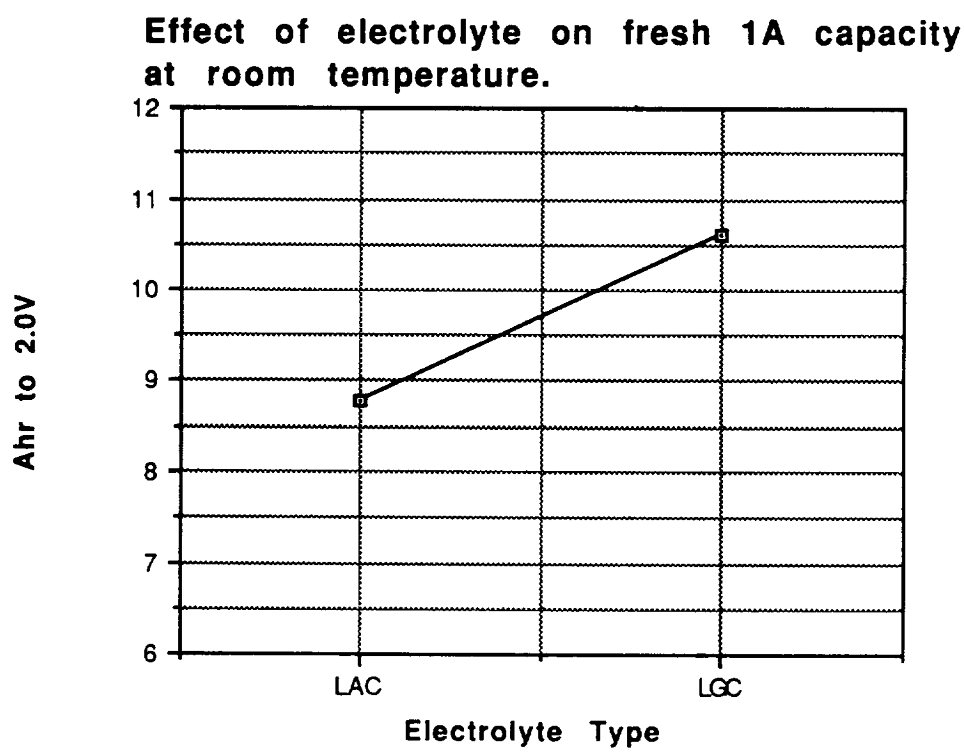

Effect of electrolyte on fresh 1A capacity at room temperature.
Ahr to 2.0V
12
11
10
9
8
7
6
LAC
LGC
Electrolyte Type

Figure 10

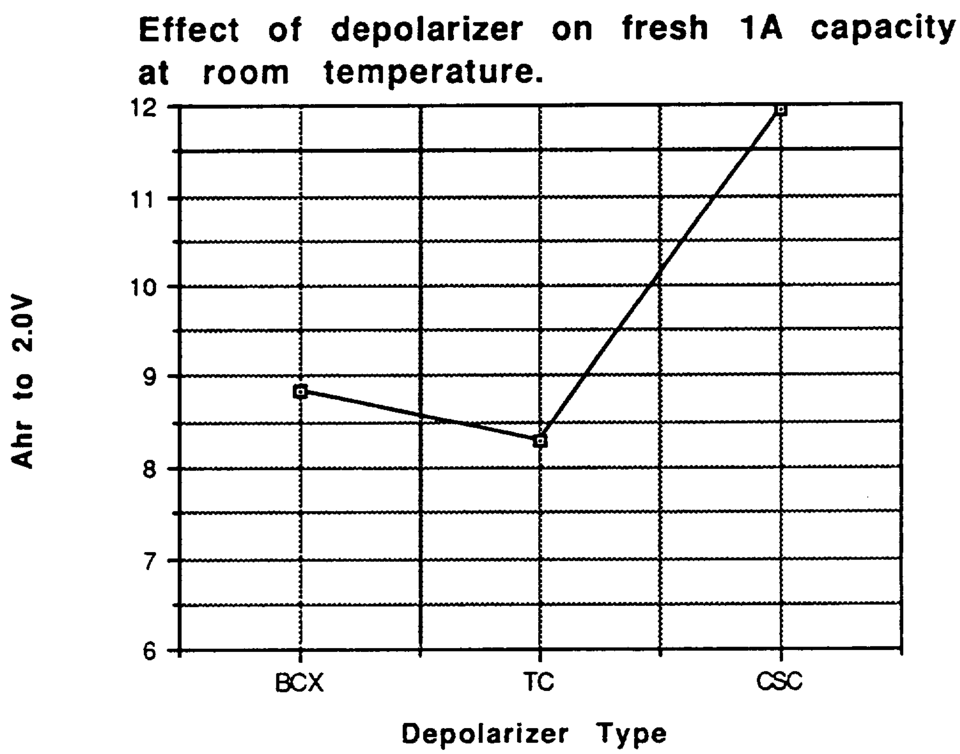
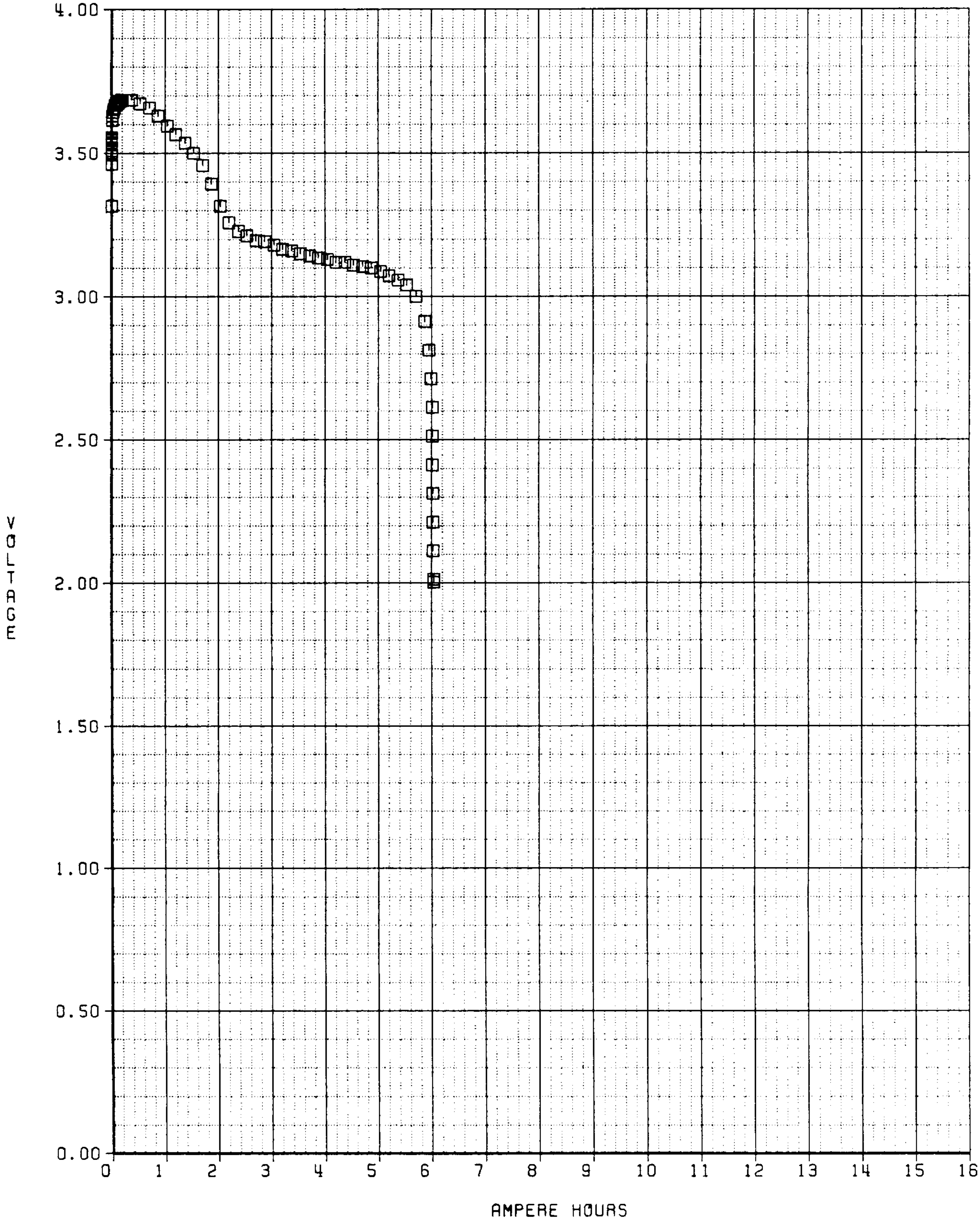

Effect of depolarizer on fresh 1A capacity at room temperature.
Ahr to 2.0V
12
11
10
9
8
7
6
BCX
TC
CSC
Depolarizer Type

Figure 11

NASA 0.6M LAC BCX D CELL
FRESH/1 AMP DISCHARGE AT RT

MACCOR3 ID 0254 OF NASA D CELL STUDY



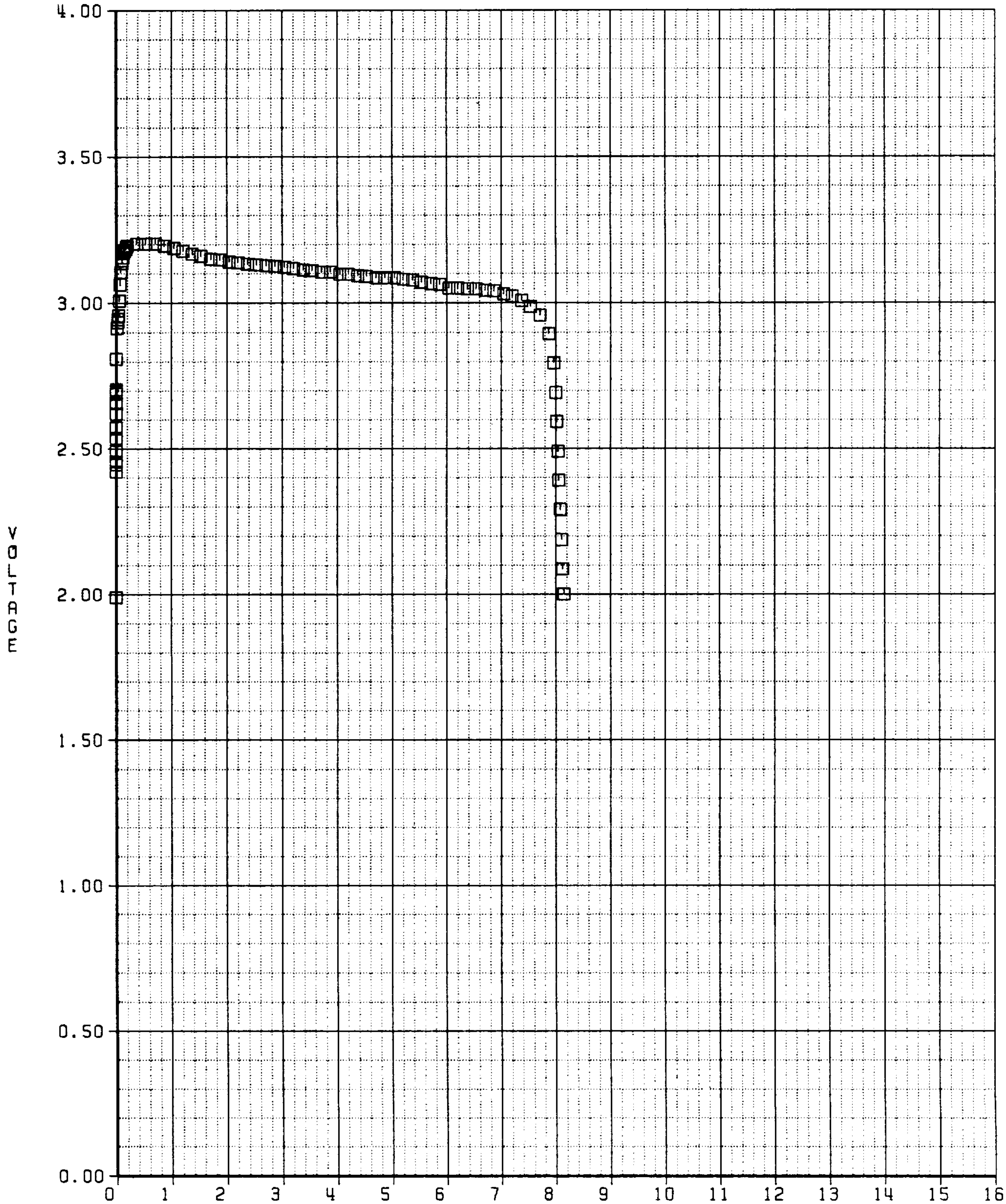
GPLOT(REV. 3.5)

DAY 054 TUE, FEB 23 1993 3:32:22 PM

Figure 12

NASA 1.2M LAC TC D CELL
FRESH/1 AMP DISCHARGE AT RT

MACCOR3 ID 0257 OF NASA D CELL STUDY



GPLOT (REV. 3.5) DAY 054 TUE. FEB 23 1993 3:35:31 PM

Figure 13

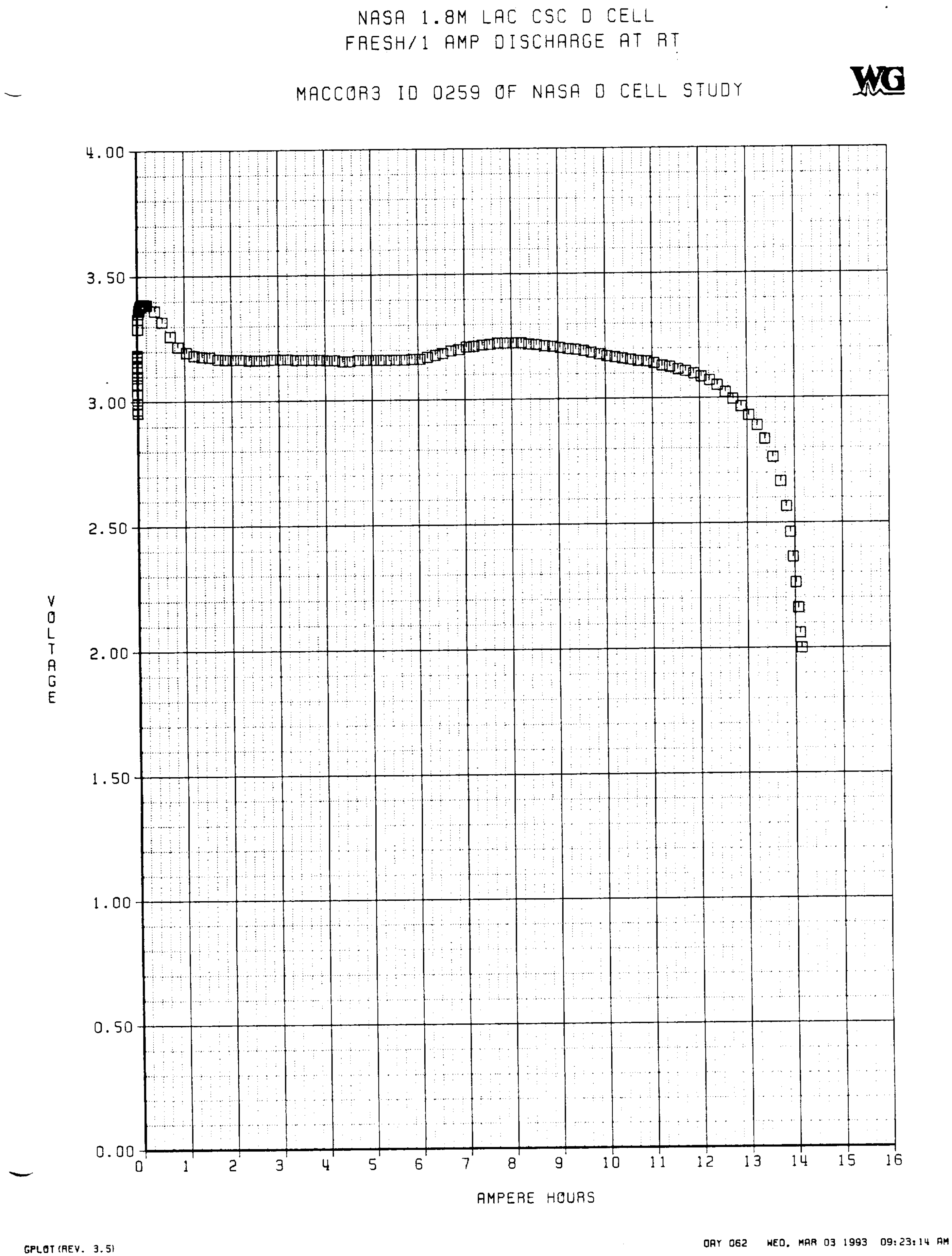

NASA 1.8M LAC CSC D CELL
FRESH/1 AMP DISCHARGE AT RT
MACCOR3 ID 0259 OF NASA D CELL STUDY
WG
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
VOLTAGE
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
AMPERE HOURS
GPLOT(REV. 3.5)
DAY 062 WED, MAR 03 1993 09:23:14 AM

Figure 14

UNIV 0.6M LAC BCX D CELL
FRESH/1 AMP DISCHARGE AT RT

MACCOR3 ID 0261 OF NASA D CELL STUDY

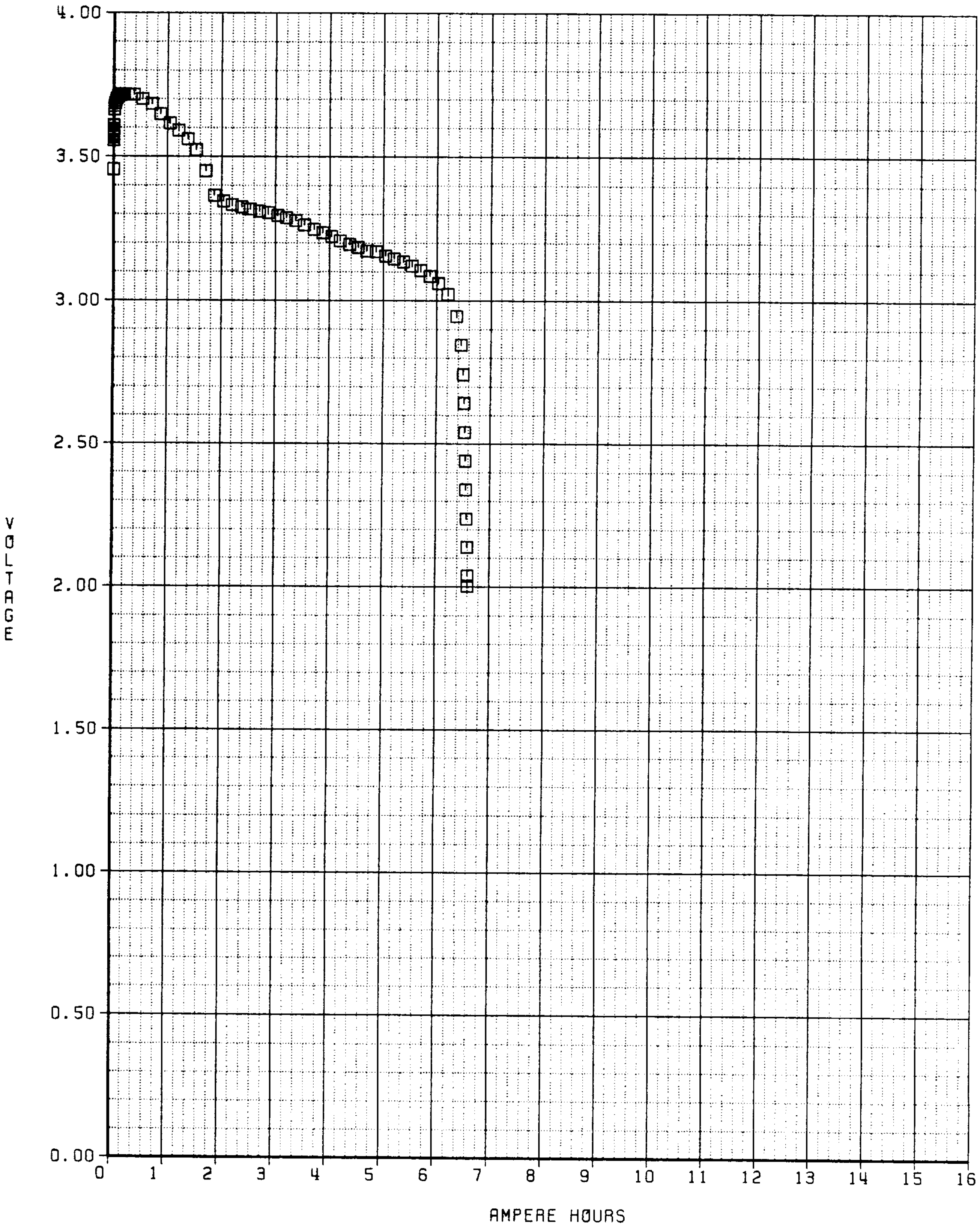
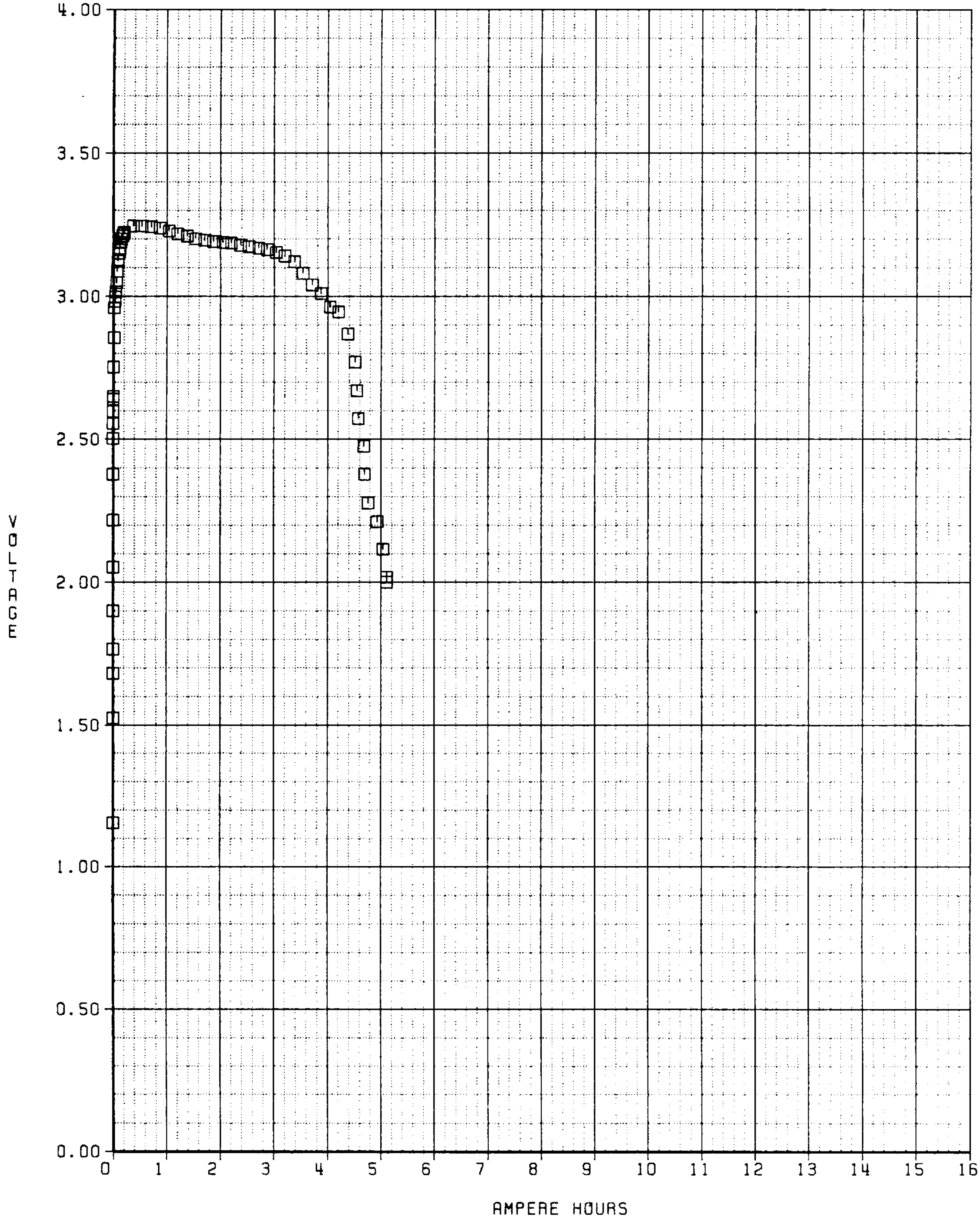


Figure 15

UNIV 1.2M LAC TC D CELL
FRESH/1 AMP DISCHARGE AT RT

MACCOR3 ID 0265 OF NASA D CELL STUDY



GPLOT (REV. 3.5)

DAY 058 SAT, FEB 27 1993 10:26:14 AM

Figure 16

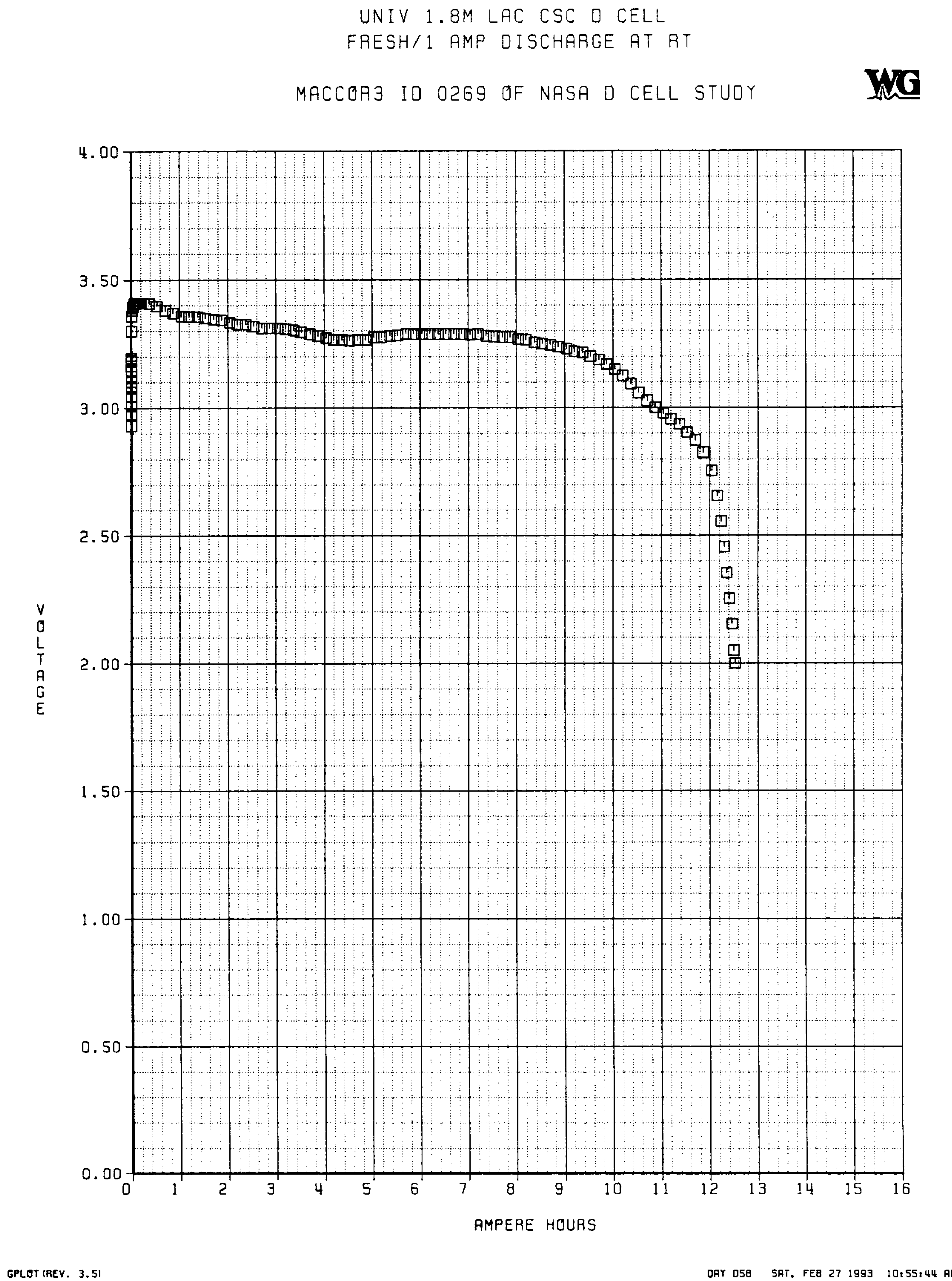

UNIV 1.8M LAC CSC D CELL
FRESH/1 AMP DISCHARGE AT RT
MACCOR3 ID 0269 OF NASA D CELL STUDY
VOLTAGE
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
AMPERE HOURS
GPLOT (REV. 3.5)
DAY 058 SAT. FEB 27 1993 10:55:44 AM

Figure 17

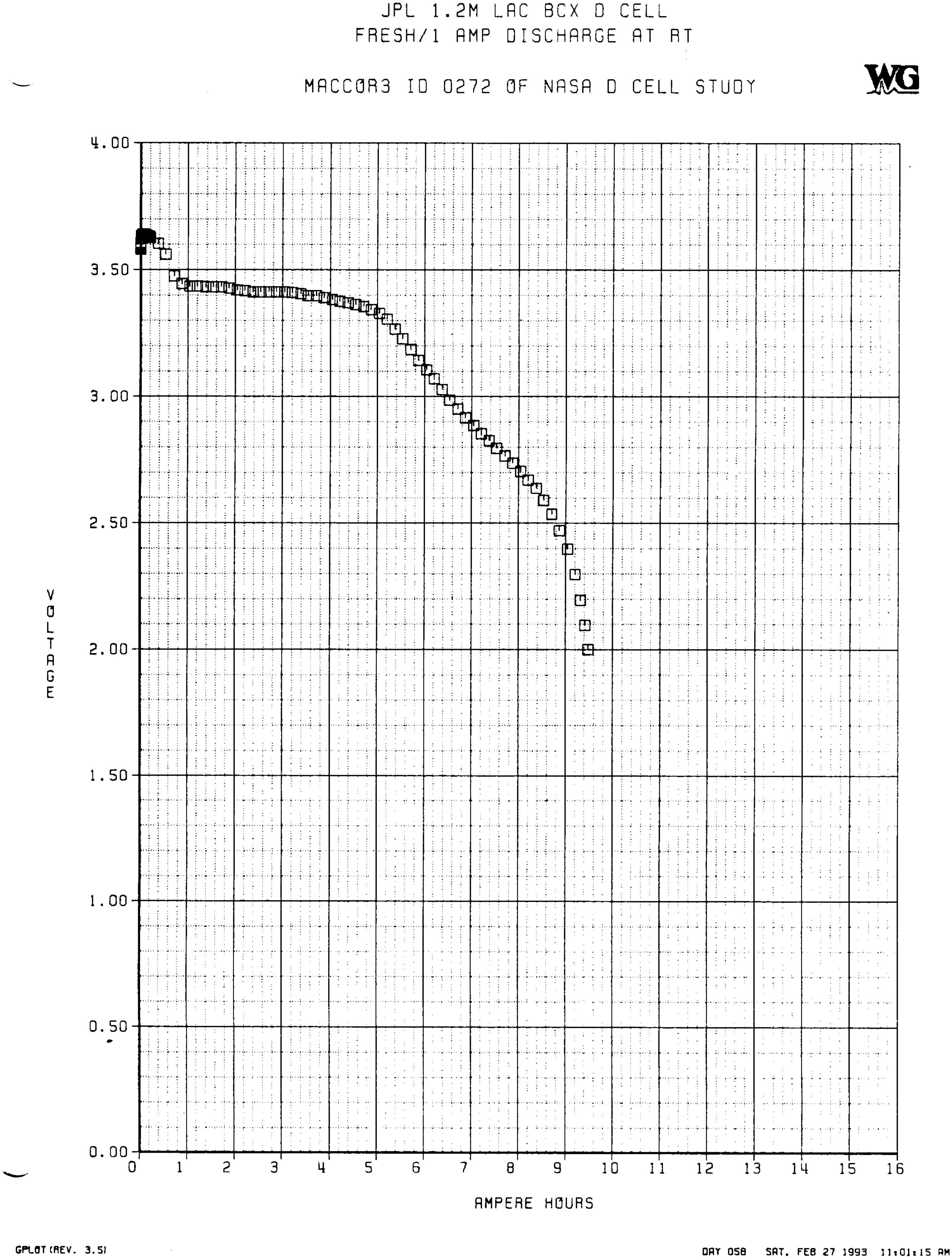
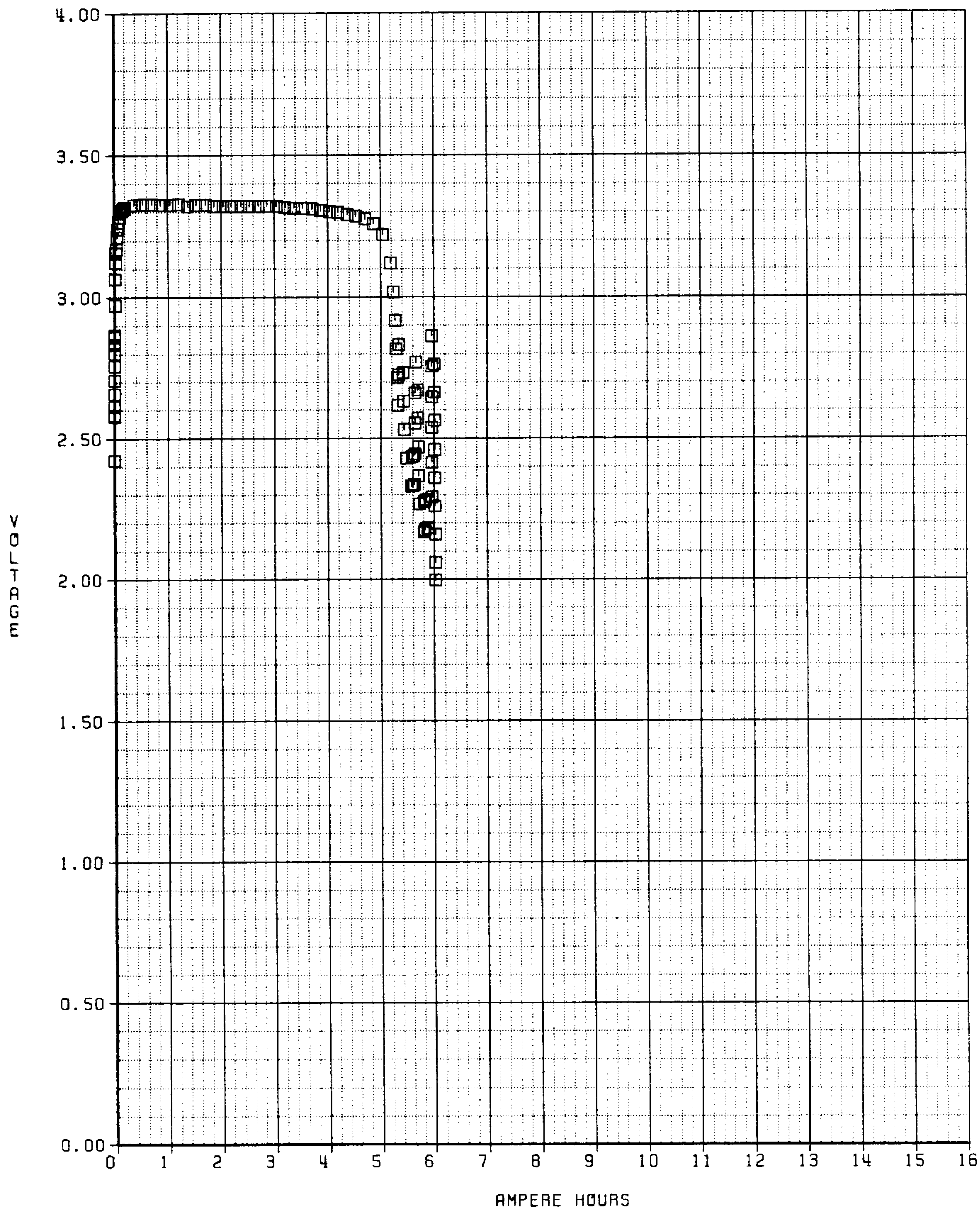

JPL 1.2M LAC BCX D CELL
FRESH/1 AMP DISCHARGE AT RT
MACCOR3 ID 0272 OF NASA D CELL STUDY
WG
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
VOLTAGE
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
AMPERE HOURS
GPLOT (REV. 3.5)
DAY 058 SAT, FEB 27 1993 11:01:15 AM

Figure 18

JPL 1.8M LAC TC D CELL
FRESH/1 AMP DISCHARGE AT RT

MACCOR3 ID 0274 OF NASA D CELL STUDY



GPLOT(REV. 3.5)

DAY 058 SAT, FEB 27 1993 11:21:40 AM

Figure 19

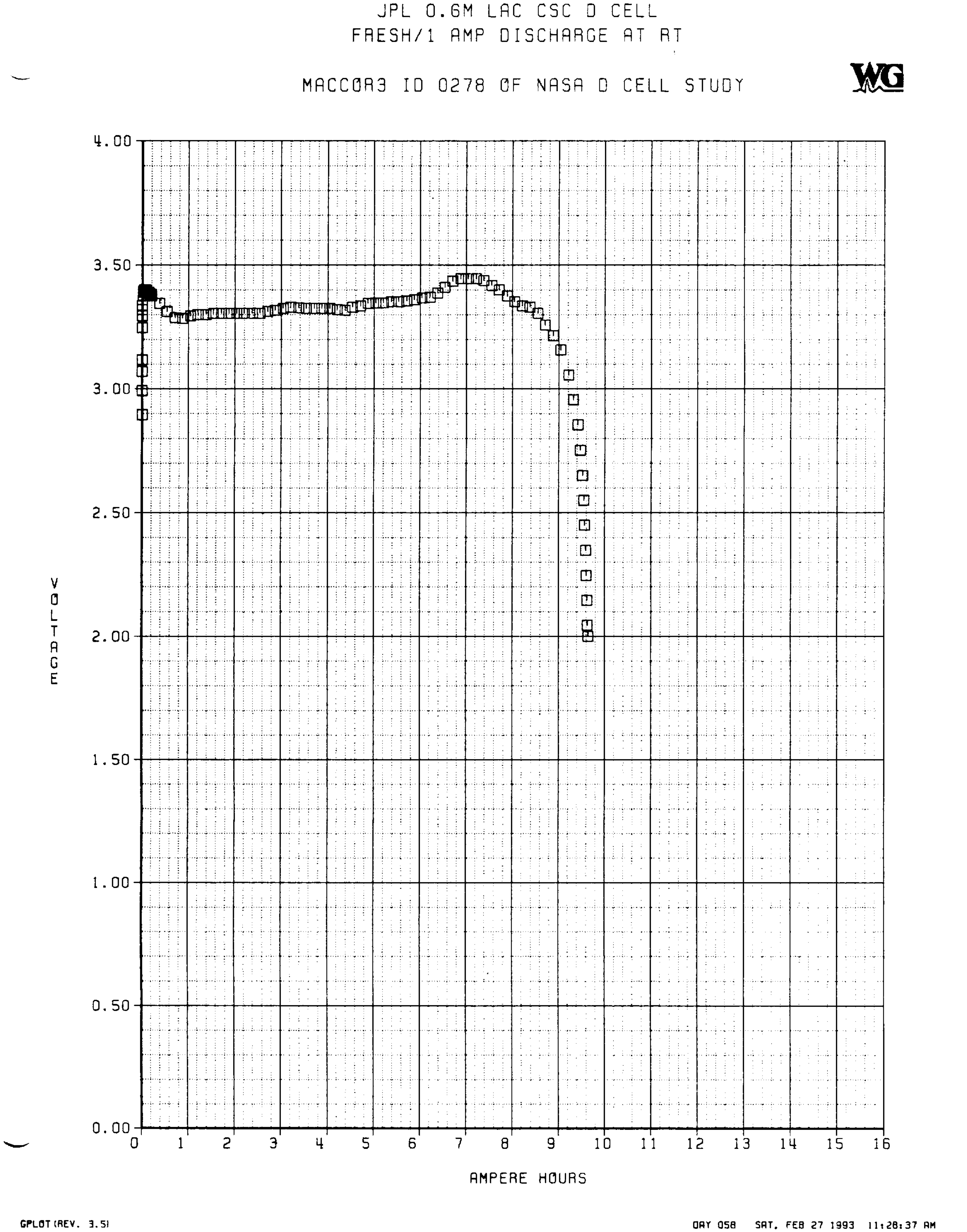

JPL 0.6M LAC CSC D CELL
FRESH/1 AMP DISCHARGE AT RT
MACCOR3 ID 0278 OF NASA D CELL STUDY
WG
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
VOLTAGE
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
AMPERE HOURS
GPLOT (REV. 3.5)
DAY 058 SAT. FEB 27 1993 11:28:37 AM

Figure 20
NASA 1.8M LGC BCX D CELL
FRESH/1 AMP DISCHARGE AT RT

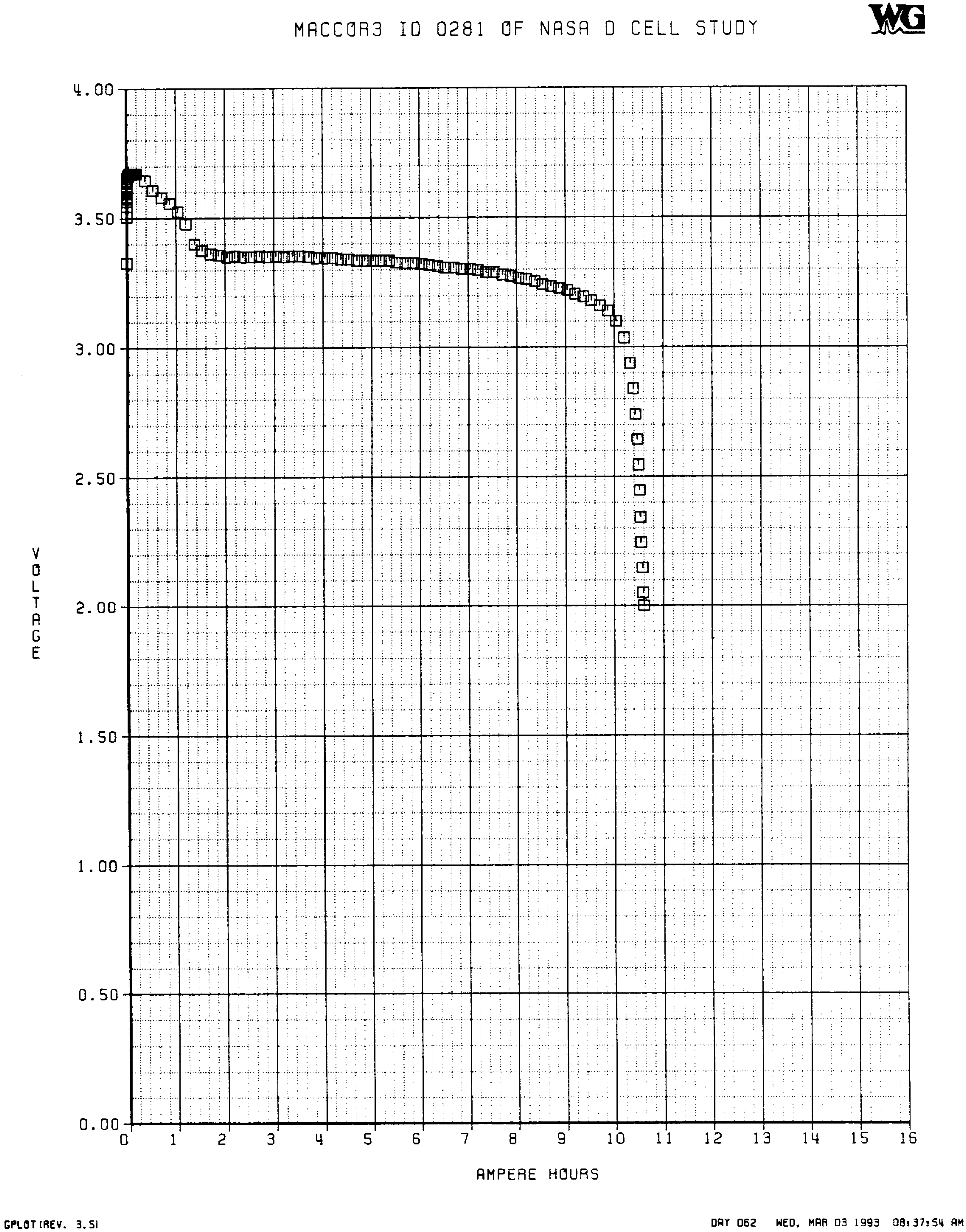
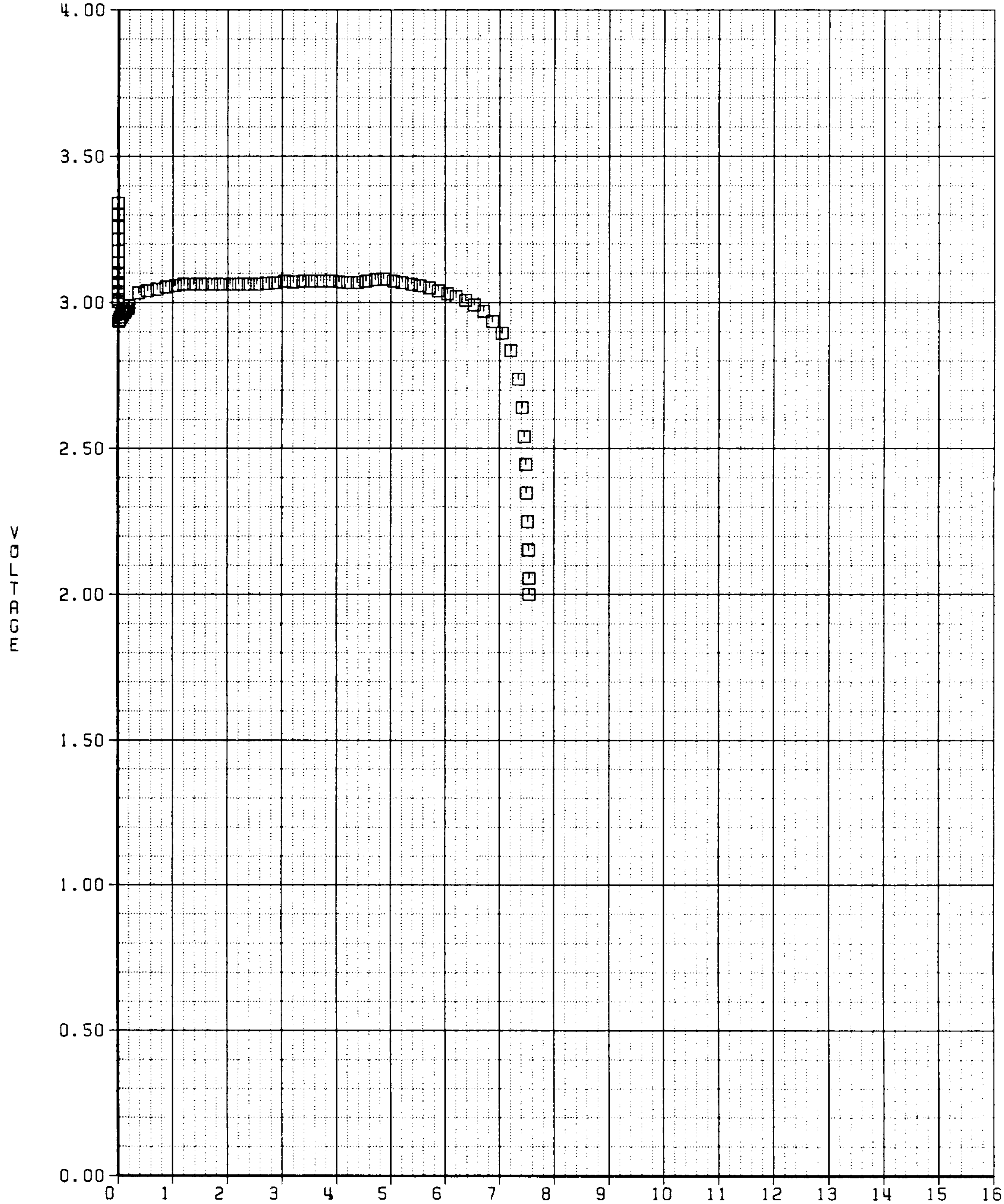


Figure 21
NASA 0.6M LGC TC D CELL
FRESH/1 AMP DISCHARGE AT RT

MACCOR3 ID 0283 OF NASA D CELL STUDY



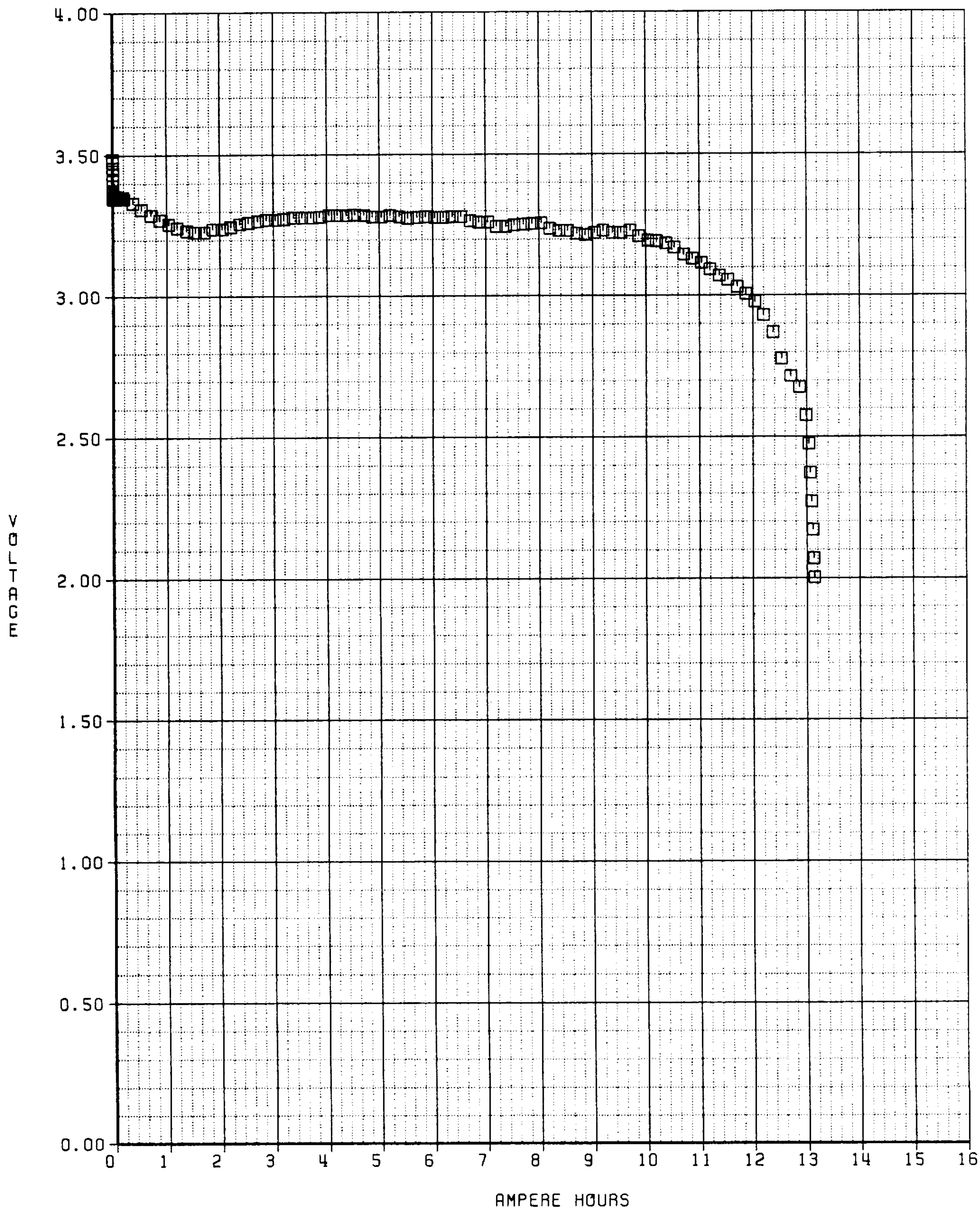
GPLOT (REV. 3.5)

DAY 061 TUE. MAR 02 1993 4:04:37 PM

Figure 22

NASA 1.2M LGC CSC D CELL
FRESH/1 AMP DISCHARGE AT RT

MACCOR3 ID 0286 OF NASA D CELL STUDY



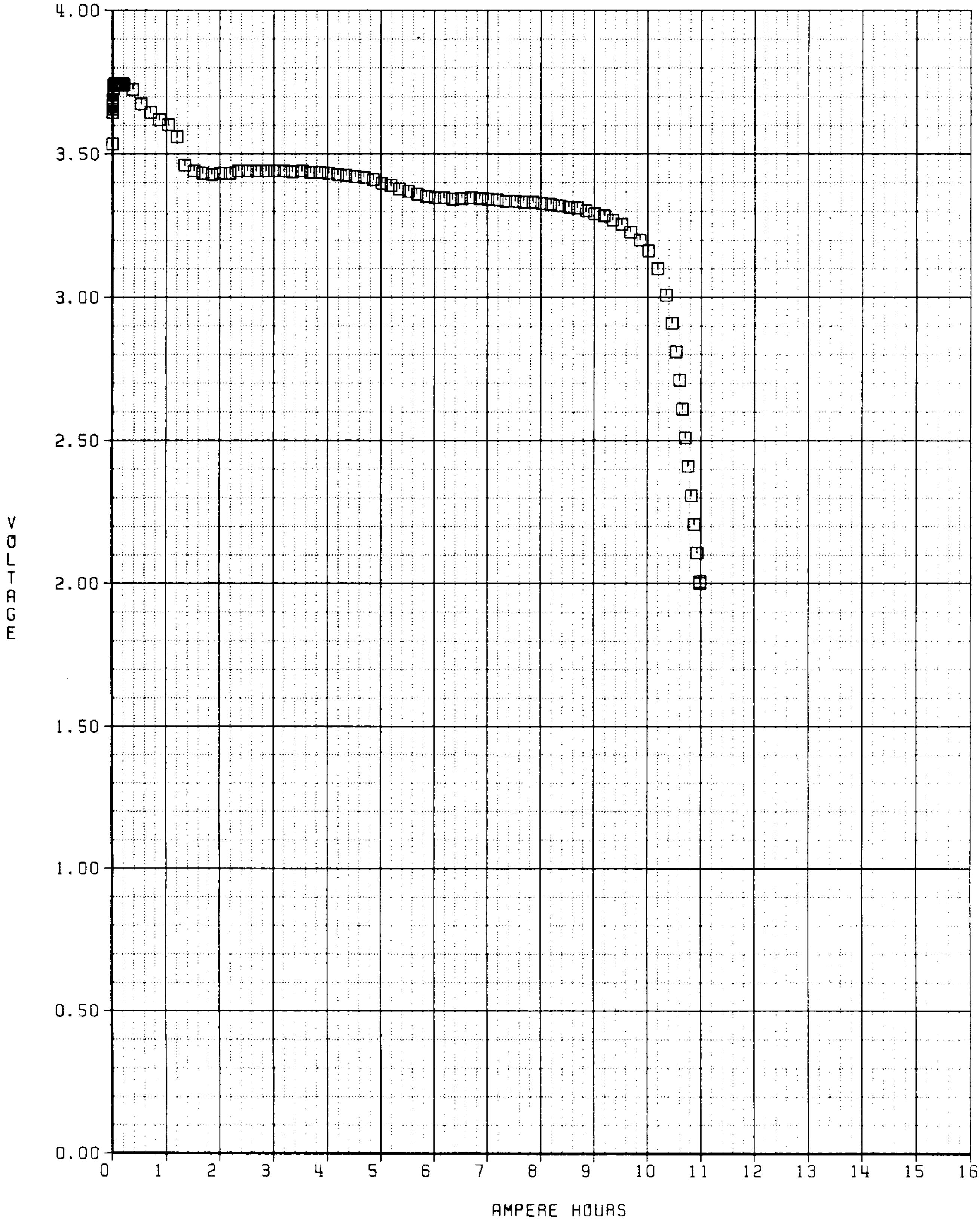
GPLOT(REV. 3.5)

DAY 061 TUE, MAR 02 1993 3:48:03 PM

Figure 23

UNIV 1.2M LGC BCX D CELL
FRESH/1 AMP DISCHARGE AT RT

MACCOR3 ID 0288 OF NASA D CELL STUDY



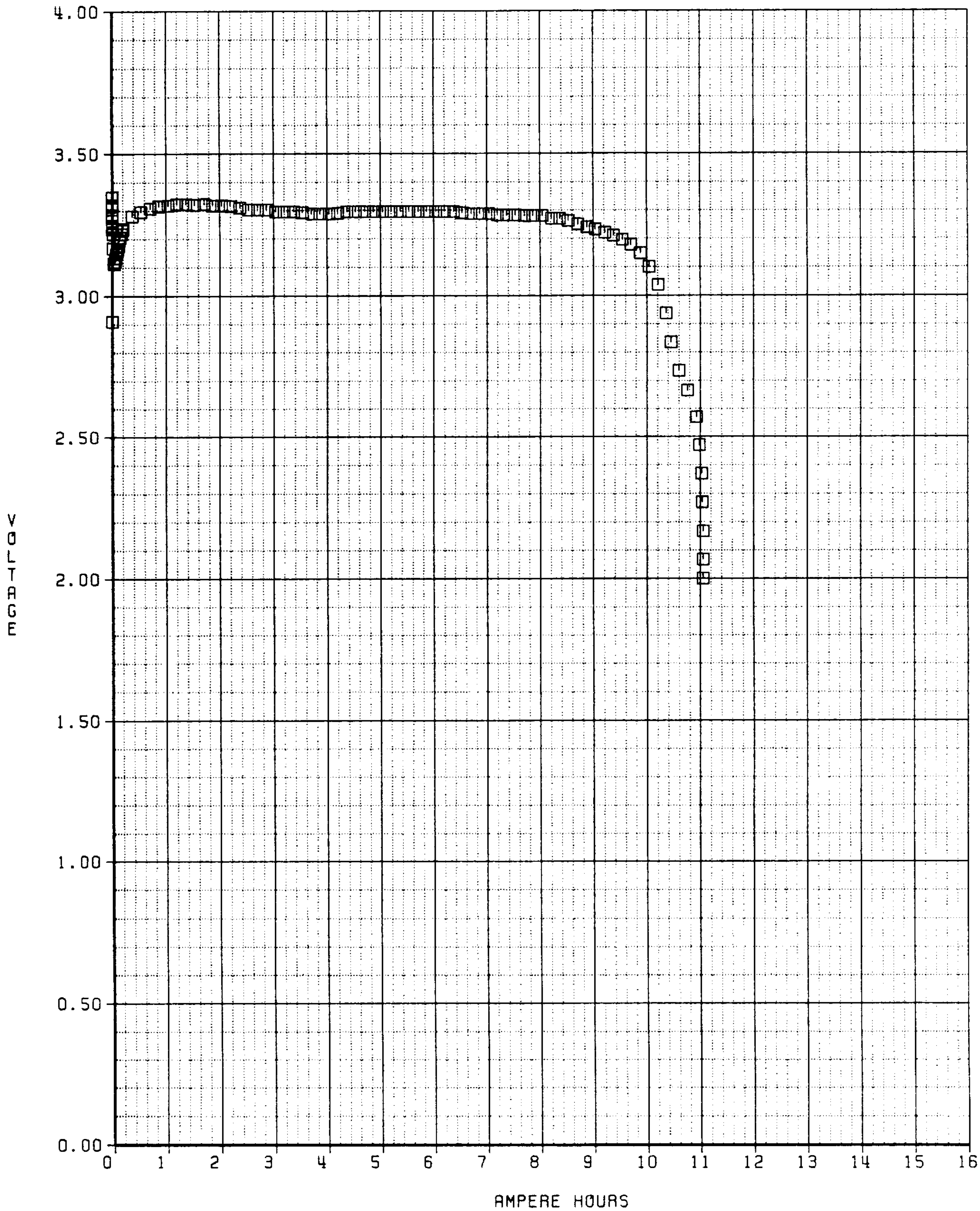
GPLOT(REV. 3.5)

DAY 062 WED, MAR 03 1993 09:18:08 AM

Figure 24

UNIV 1.8M LGC TC D CELL
FRESH/1 AMP DISCHARGE AT RT

MACCOR3 ID 0291 OF NASA D CELL STUDY



GPLOT (REV. 3.5)

DAY 061 TUE. MAR 02 1993 09:58:49 AM

Figure 25

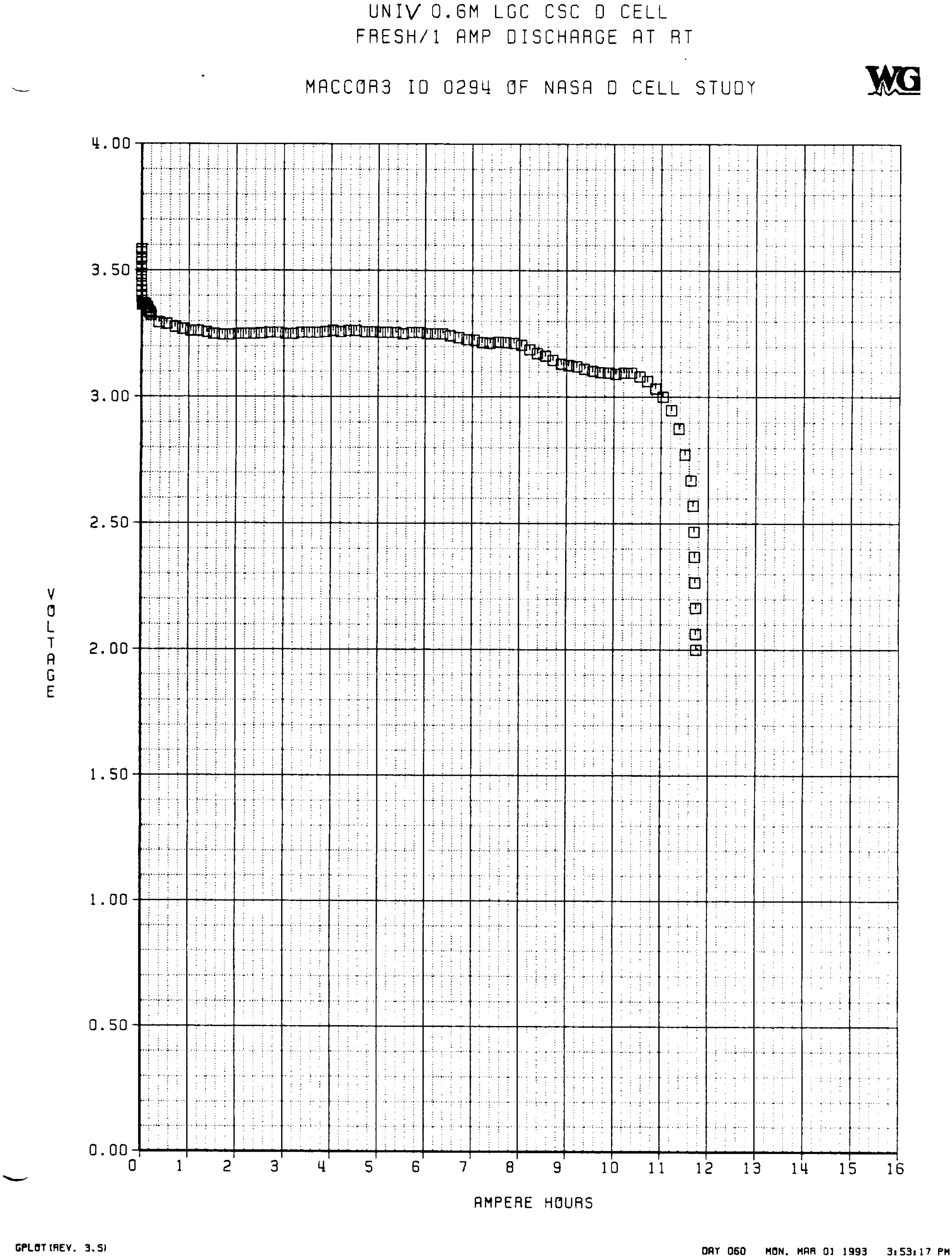
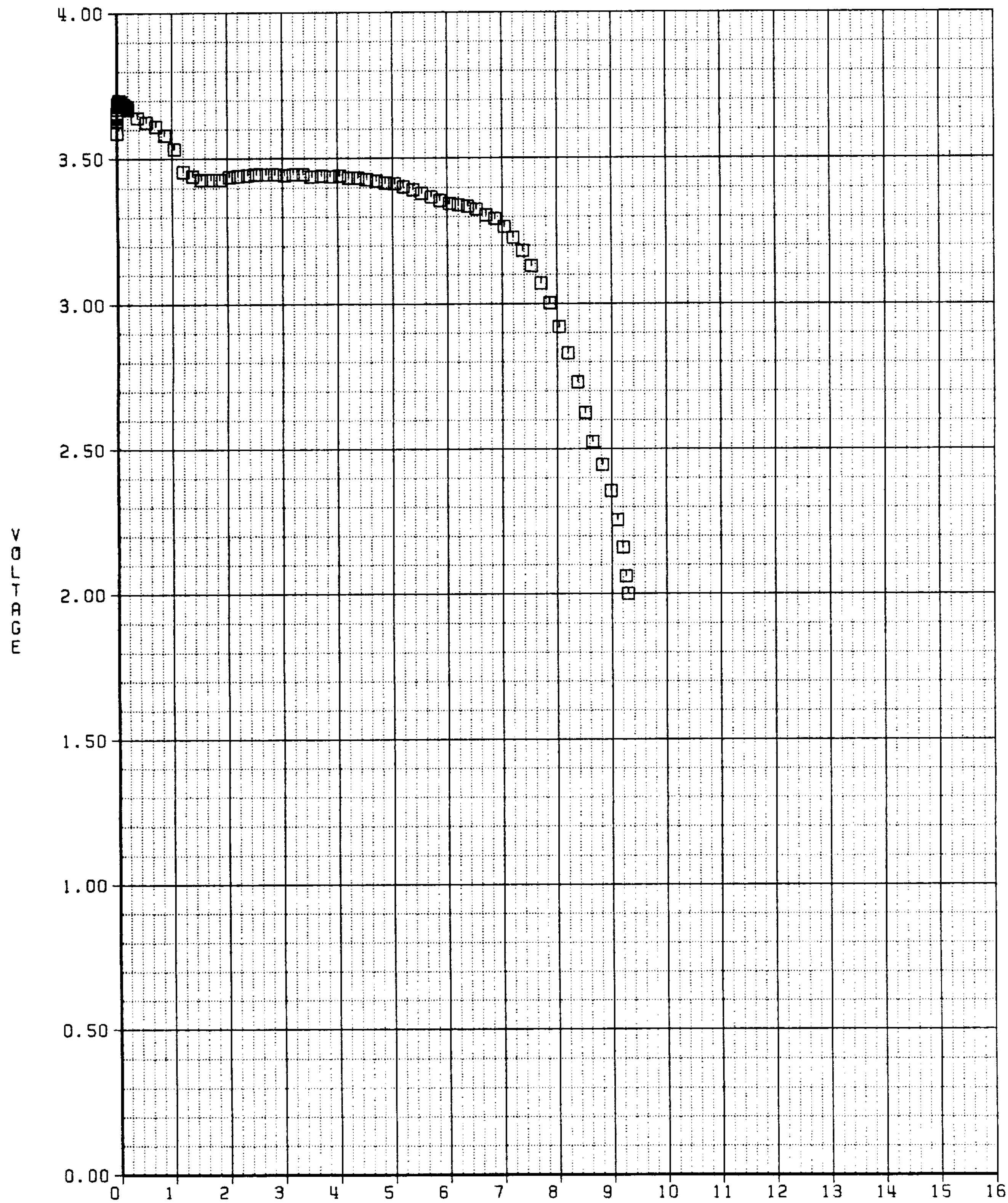

UNIV 0.6M LGC CSC D CELL
FRESH/1 AMP DISCHARGE AT RT
MACCOR3 ID 0294 OF NASA D CELL STUDY
WG
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
VOLTAGE
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
AMPERE HOURS
GPLOT (REV. 3.5)
DAY 060 MON. MAR 01 1993 3:53:17 PM

Figure 26

JPL 1.8M LGC BCX D CELL
FRESH/1 AMP DISCHARGE AT RT

MACCOR3 ID 0297 OF NASA D CELL STUDY



GPLOT (REV. 3.5)

DAY 058 SAT, FEB 27 1993 11:46:55 AM

Figure 27

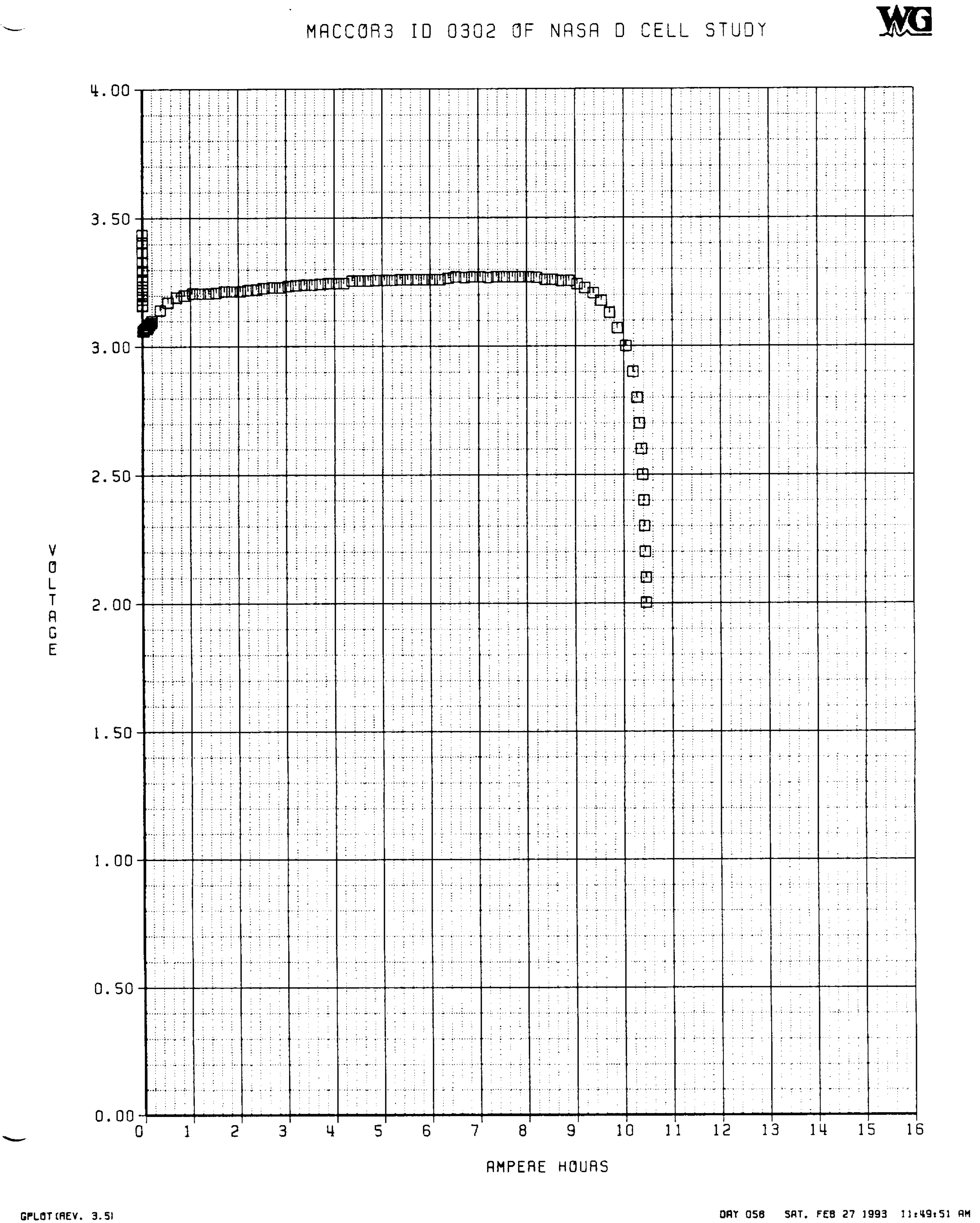
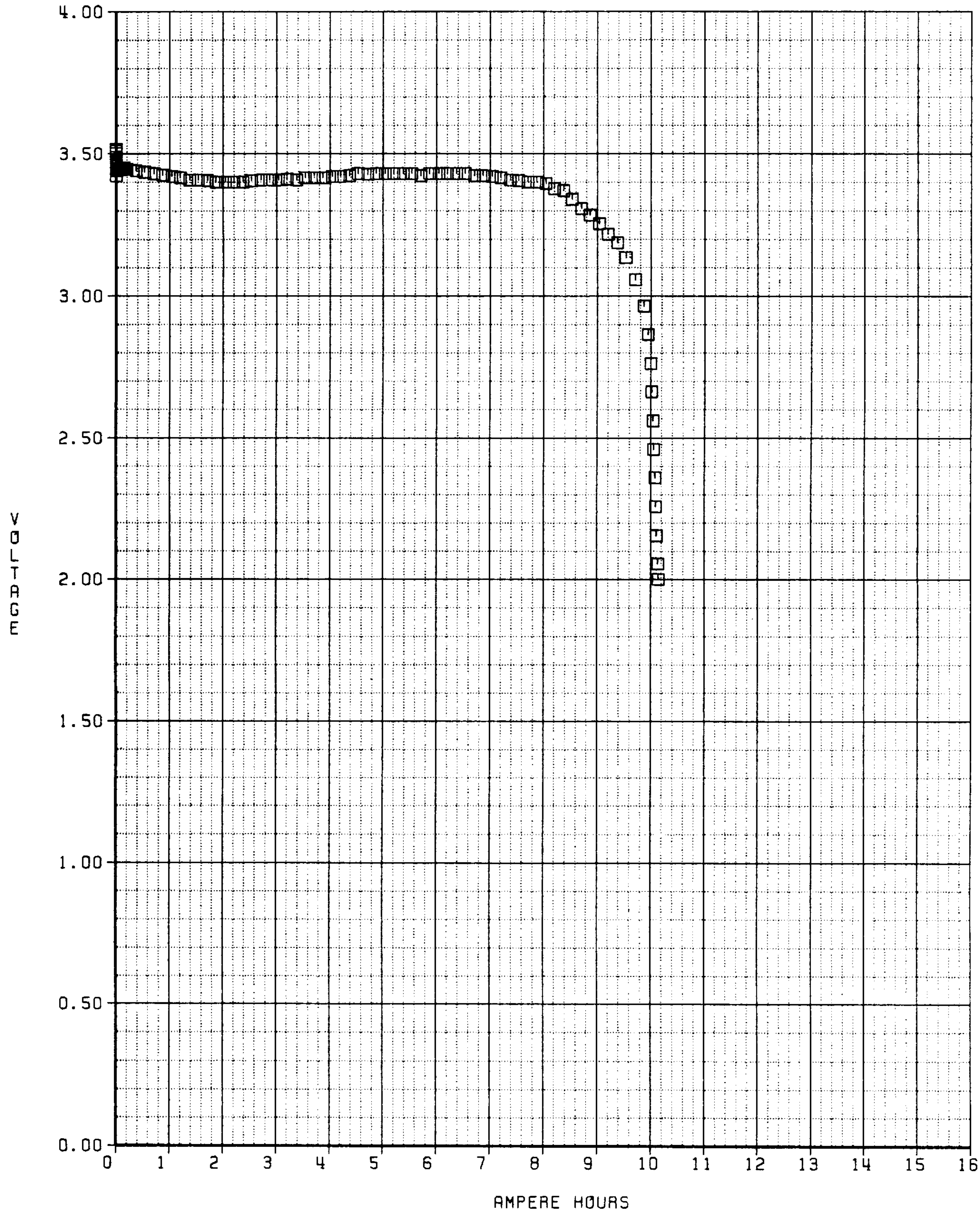

JPL 0.6M LGC TC D CELL
FRESH/1 AMP DISCHARGE AT RT
MACCOR3 ID 0302 OF NASA D CELL STUDY
WG
VOLTAGE
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
AMPERE HOURS
GPLOT(REV. 3.5)
DAY 058 SAT. FEB 27 1993 11:49:51 AM

Figure 28

JPL 1.2M LGC CSC D CELL
FRESH/1 AMP DISCHARGE AT RT

MACCOR3 ID 0305 OF NASA D CELL STUDY



GPLOT (REV. 3.5)

DAY 060 MON. MAR 01 1993 3:49:30 PM

Figure 29

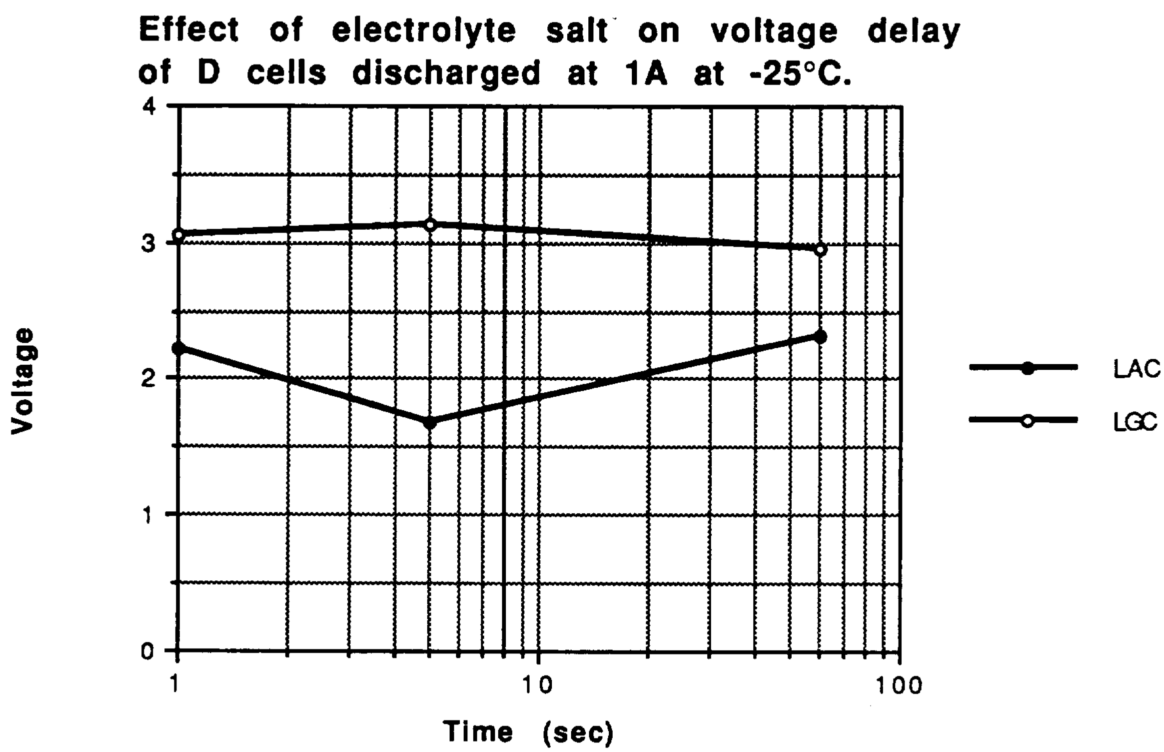

Effect of electrolyte salt on voltage delay of D cells discharged at 1A at -25°C.
Voltage
4
3
2
1
0
1
10
100
Time (sec)
LAC
LGC

Figure 30

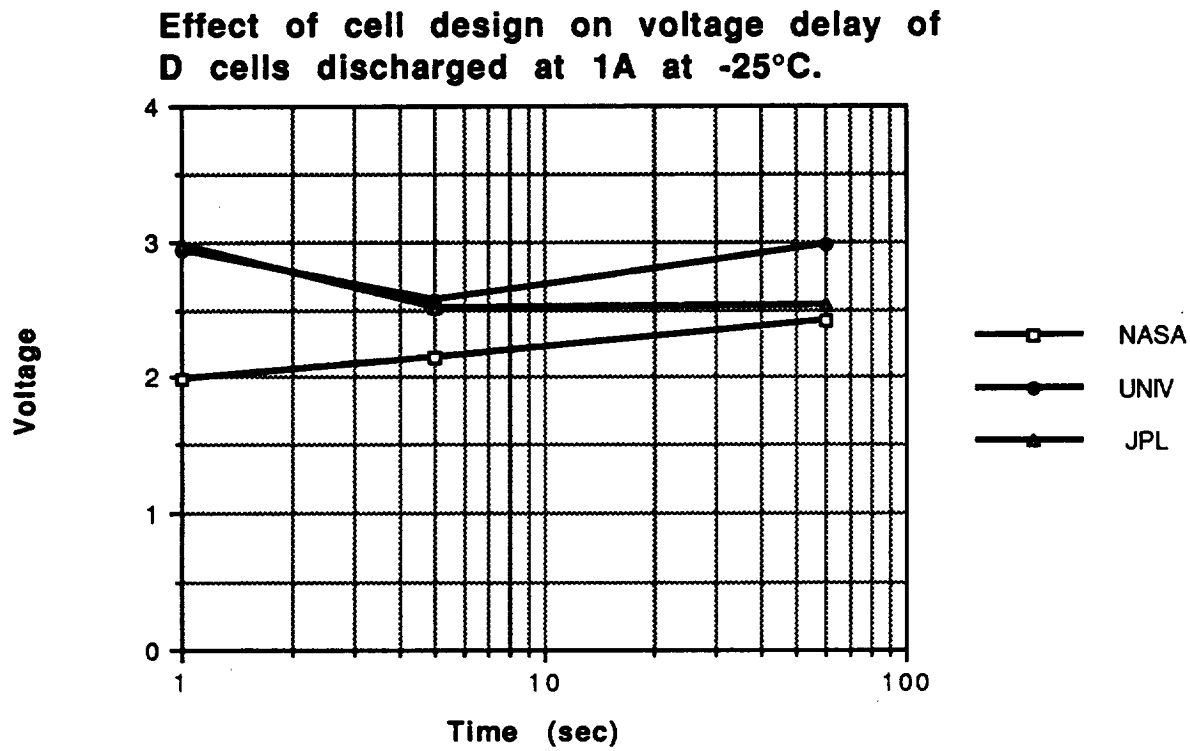

Effect of cell design on voltage delay of
D cells discharged at 1A at -25°C.
Voltage
4
3
2
1
0
1
10
100
Time (sec)
NASA
UNIV
JPL

Figure 31

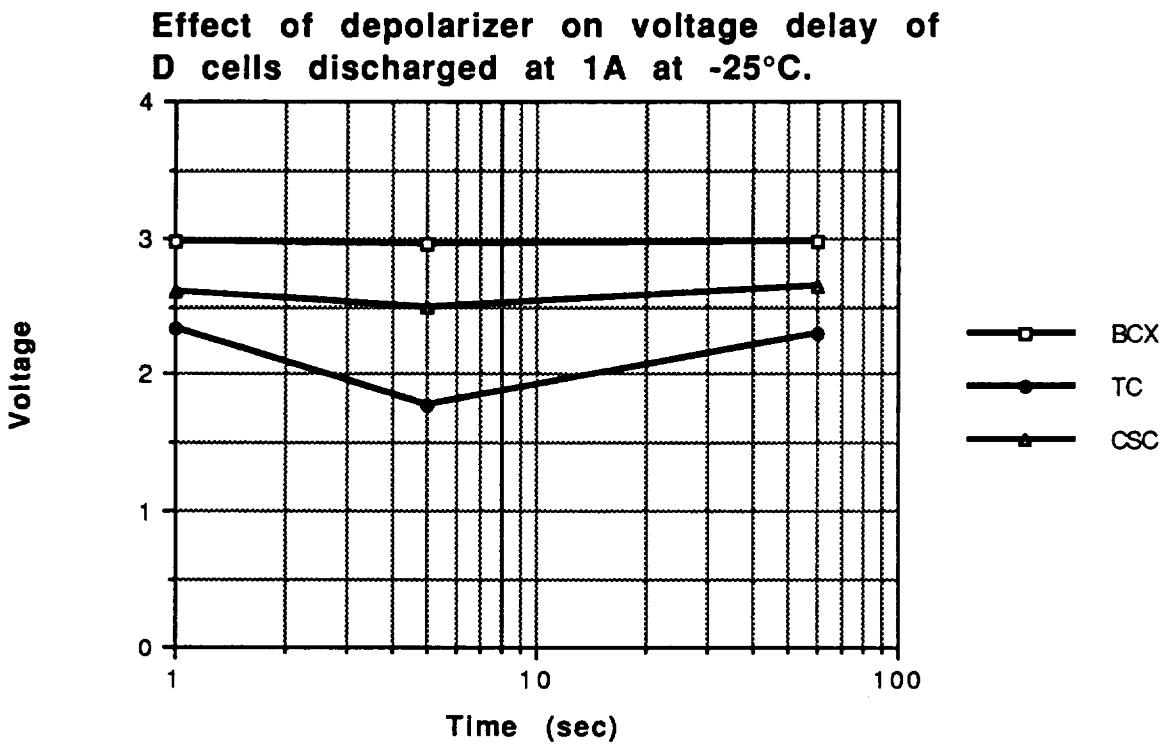

Effect of depolarizer on voltage delay of D cells discharged at 1A at -25°C.
Voltage
4
3
2
1
0
1
10
100
Time (sec)
BCX
TC
CSC

Figure 32

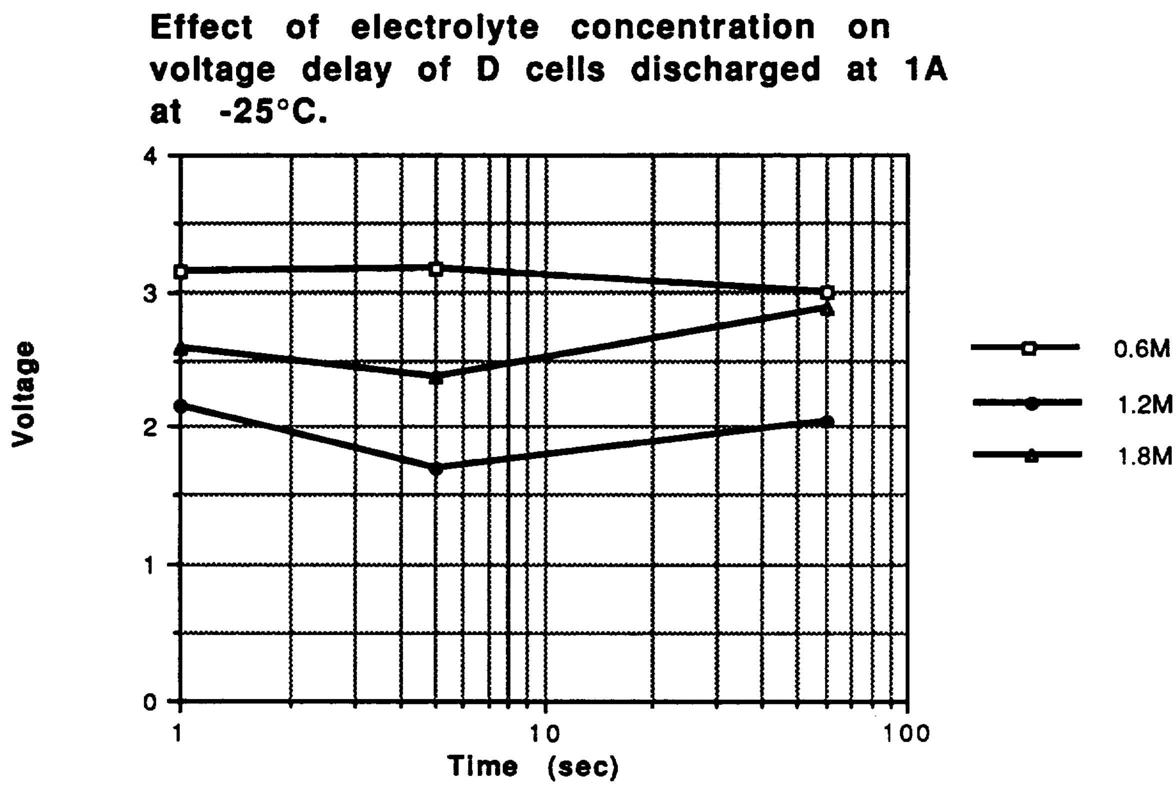

Effect of electrolyte concentration on voltage delay of D cells discharged at 1A at -25°C.
Voltage
4
3
2
1
0
1
10
100
Time (sec)
0.6M
1.2M
1.8M

Figure 33

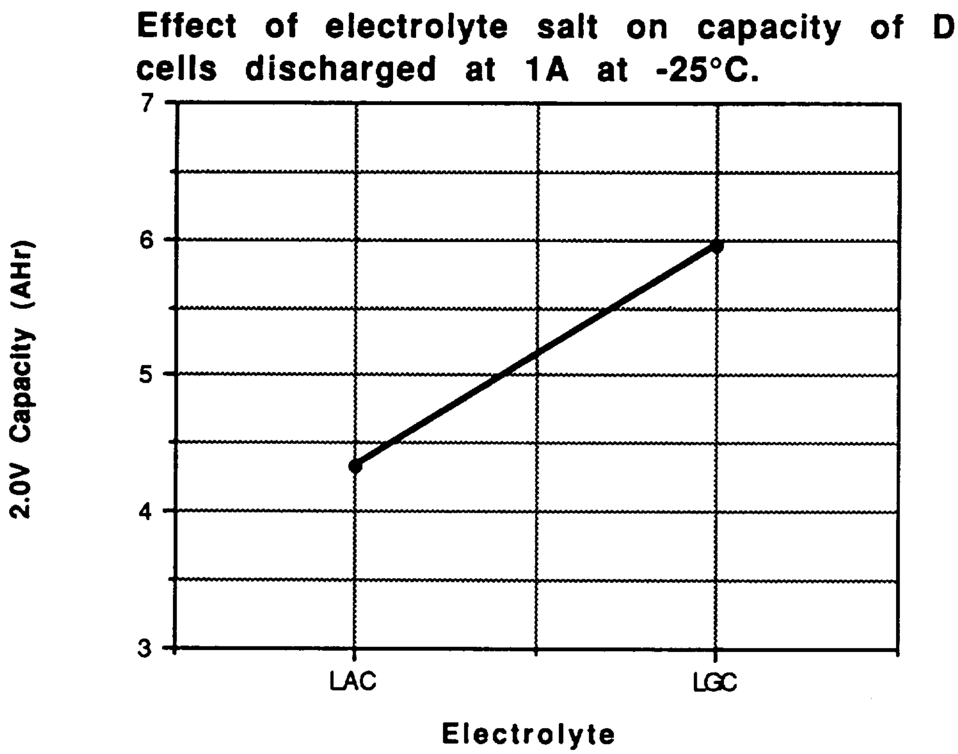

Effect of electrolyte salt on capacity of D cells discharged at 1A at -25°C.
7
6
5
4
3
2.0V Capacity (AHr)
LAC
LGC
Electrolyte

Figure 34

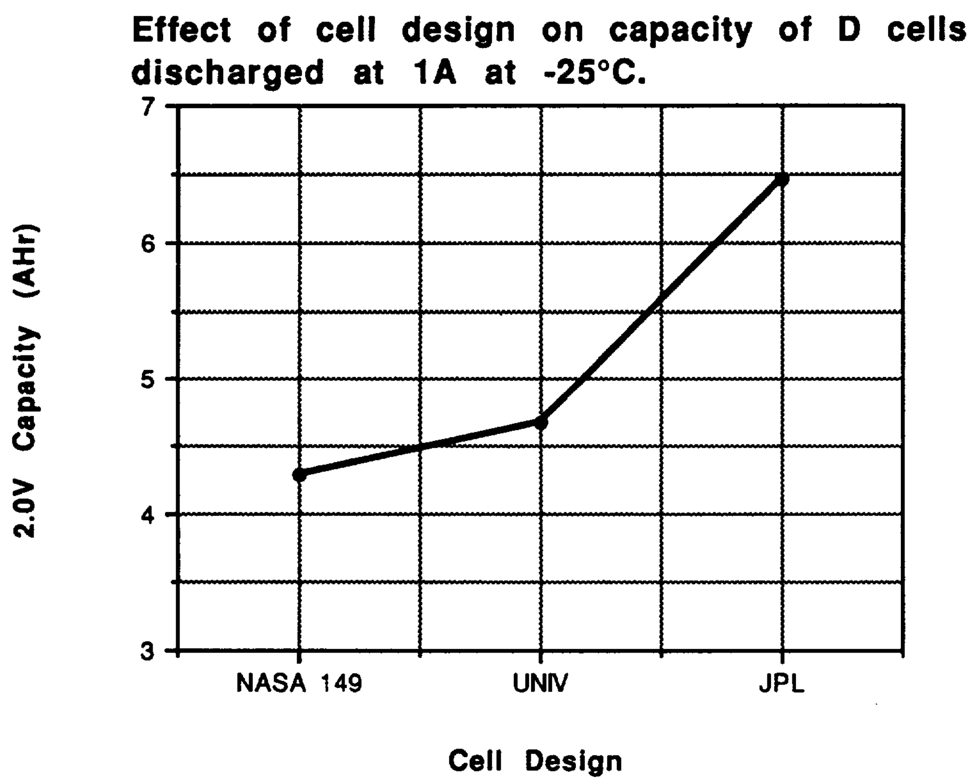

Effect of cell design on capacity of D cells discharged at 1A at -25°C.
2.0V Capacity (AHr)
7
6
5
4
3
NASA 149
UNIV
JPL
Cell Design

Figure 35

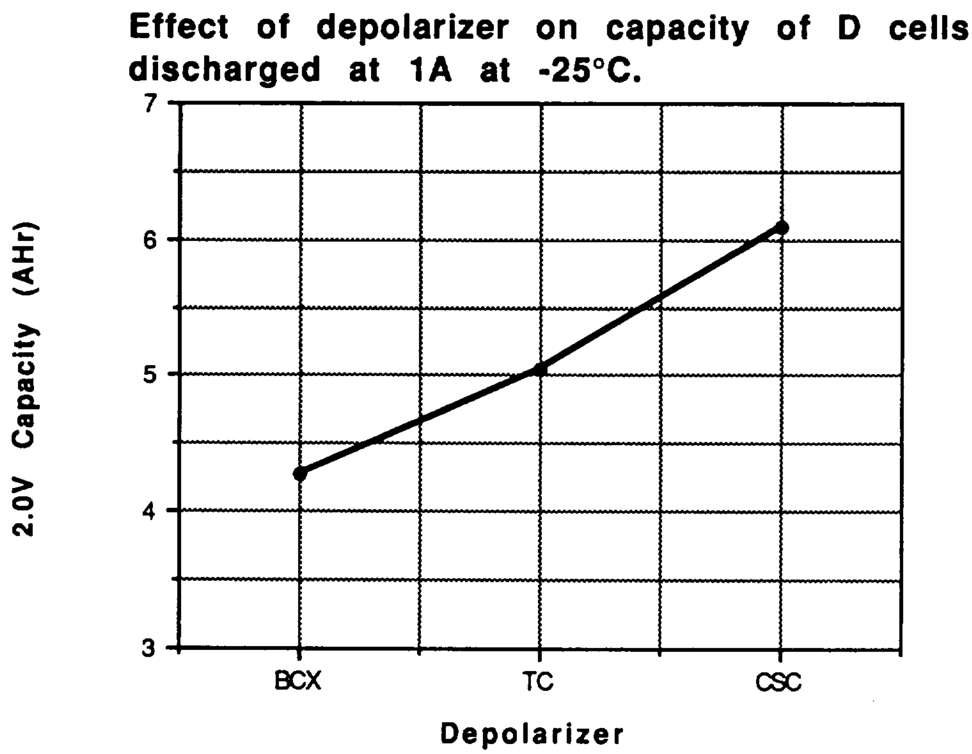
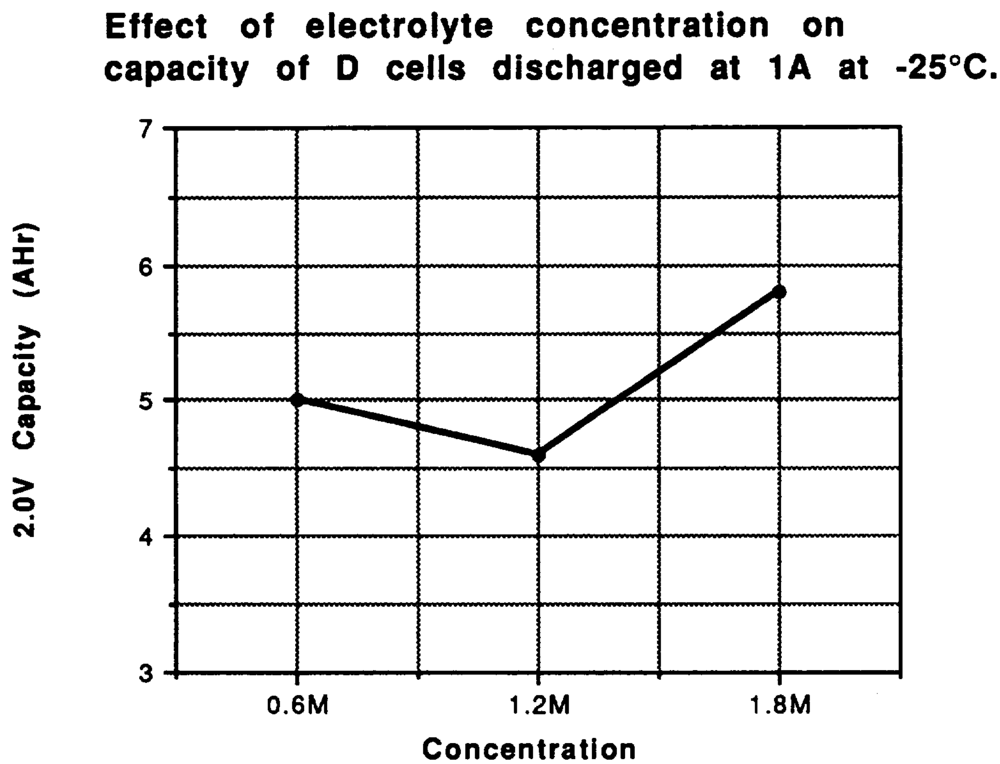

Effect of depolarizer on capacity of D cells discharged at 1A at -25°C.
2.0V Capacity (AHr)
7
6
5
4
3
BCX
TC
CSC
Depolarizer

Figure 36


Effect of electrolyte concentration on capacity of D cells discharged at 1A at -25°C.
2.0V Capacity (AHr)
7
6
5
4
3
0.6M
1.2M
1.8M
Concentration

36 illustrate the main effects of the four factors in delivered capacity. They show that the LGC electrolyte is favored over the LAC electrolyte, and the JPL design is favored over the UNIV and the NASA design. CSC depolarizer was favored, as was the high molarity electrolyte, but caution should be exercised in assessing these two factors, since their overall contribution was 6.2 and 1.3%, respectively. Figures 37 - 54 are representative discharge curves for the 18 configurations tested under this set of conditions, and the ANOVA reports are included in Appendix C.

5.3 FRESH 3A ROOM TEMPERATURE PERFORMANCE

Under 3A room temperature conditions, the start up characteristics of the cells were initially influenced the most by the electrolyte salt. The overall affect of the electrolyte type was a 43% contribution to the 1 second voltage variation, and the LGC salt produced a 100% improvement in the starting voltage of the cells. Several cells containing the LAC salt did not recover within the first 5 seconds, and the average voltage after 60 seconds was 2.84V for cells with LAC electrolyte compared to 3.07V for cells with the LGC salt. Figure 55 illustrates the effect of the electrolyte salt on voltage delay of D cells. The depolarizer type had a 17.9% effect on initial start up voltage and this is illustrated in figure 56. BCX depolarizer produces better start up voltages then either CSC or TC depolarizers. The 60 second voltage is mostly affected by the depolarizer (37%) and again the cells with BCX depolarizer recover to higher voltages than cells with CSC or TC. The cell design has little to no effect on voltage delay under these conditions, and the electrolyte concentration plays somewhat of a role in the 5 second voltage (18.8%). See figures 57 & 58.

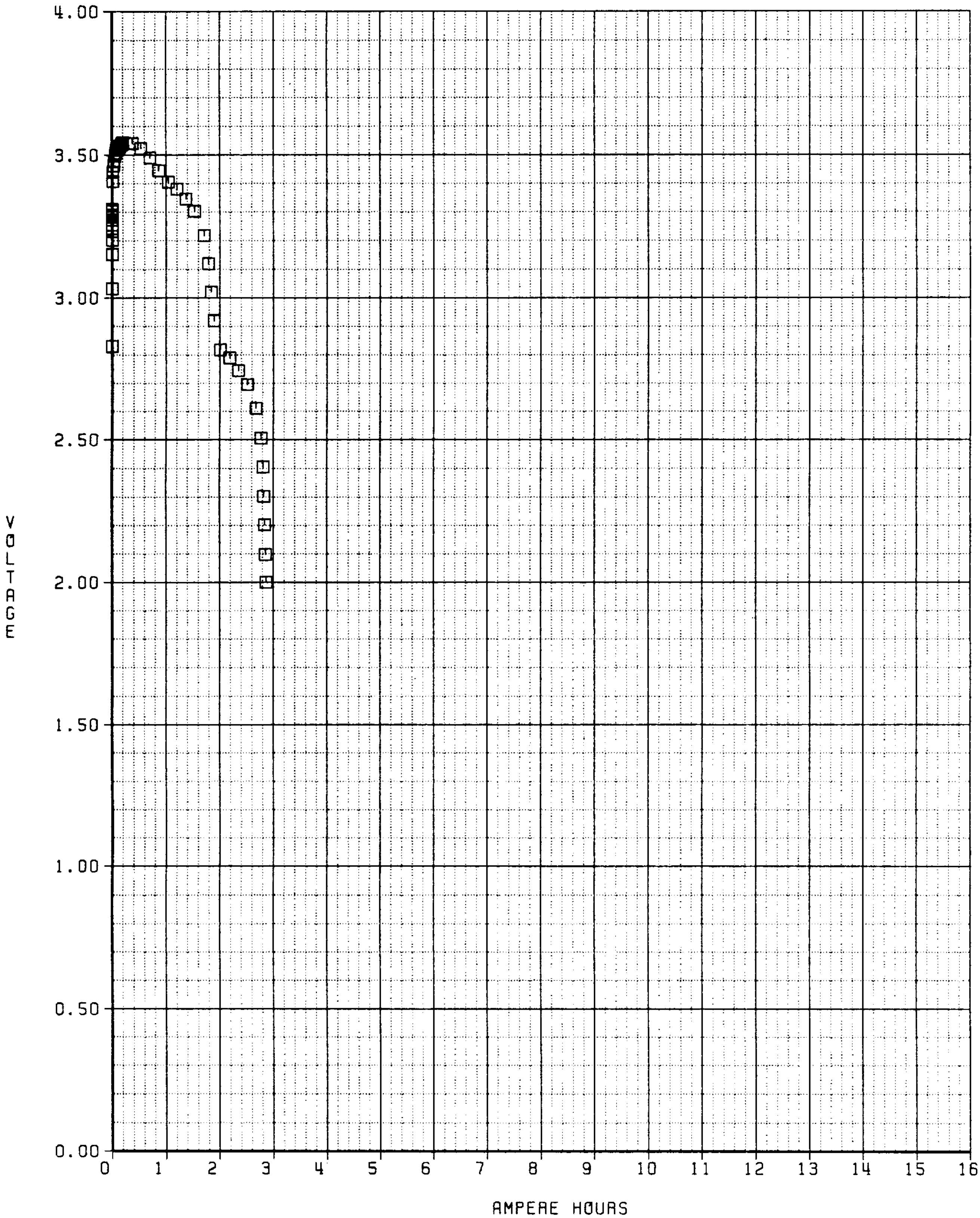
The factor having the largest effect on running voltage was the depolarizer type (25%). However, the outside noises in the experiment accounted for 72% of the variation. Figure 59 illustrates that the CSC depolarizer offers the highest running voltage of the three depolarizers studied (3.26V). The remaining three factors in the experiment had 0 - 3% effect on running voltage.

The three factors affecting delivered capacity were cell design, depolarizer, and electrolyte concentration, contributing 19.5%, 35.9% and 23.4%, respectively. Figure 60 shows that the JPL design delivered the highest capacities of the three designs (9.17 Ah) and the NASA design delivered the lowest (6.25 Ah). In figure 61, it can be seen that the CSC depolarizer has the best high rate performance of the three electrolytes, delivering an average of 10.33 Ah to 2.0V. BCX cells delivered 6.28 Ah and TC cells delivered 7.43 Ah to 2.0V. The effect of the electrolyte concentration is illustrated in figure 62 where it is shown that the highest molarity electrolyte delivered the highest capacities.

Figure 37

NASA 0.6M LAC BCX D CELL
FRESH/1 AMP DISCHARGE AT -25°C

MACCOR3 ID 0552 OF NASA D CELL STUDY



GPLOT (REV. 3.5)

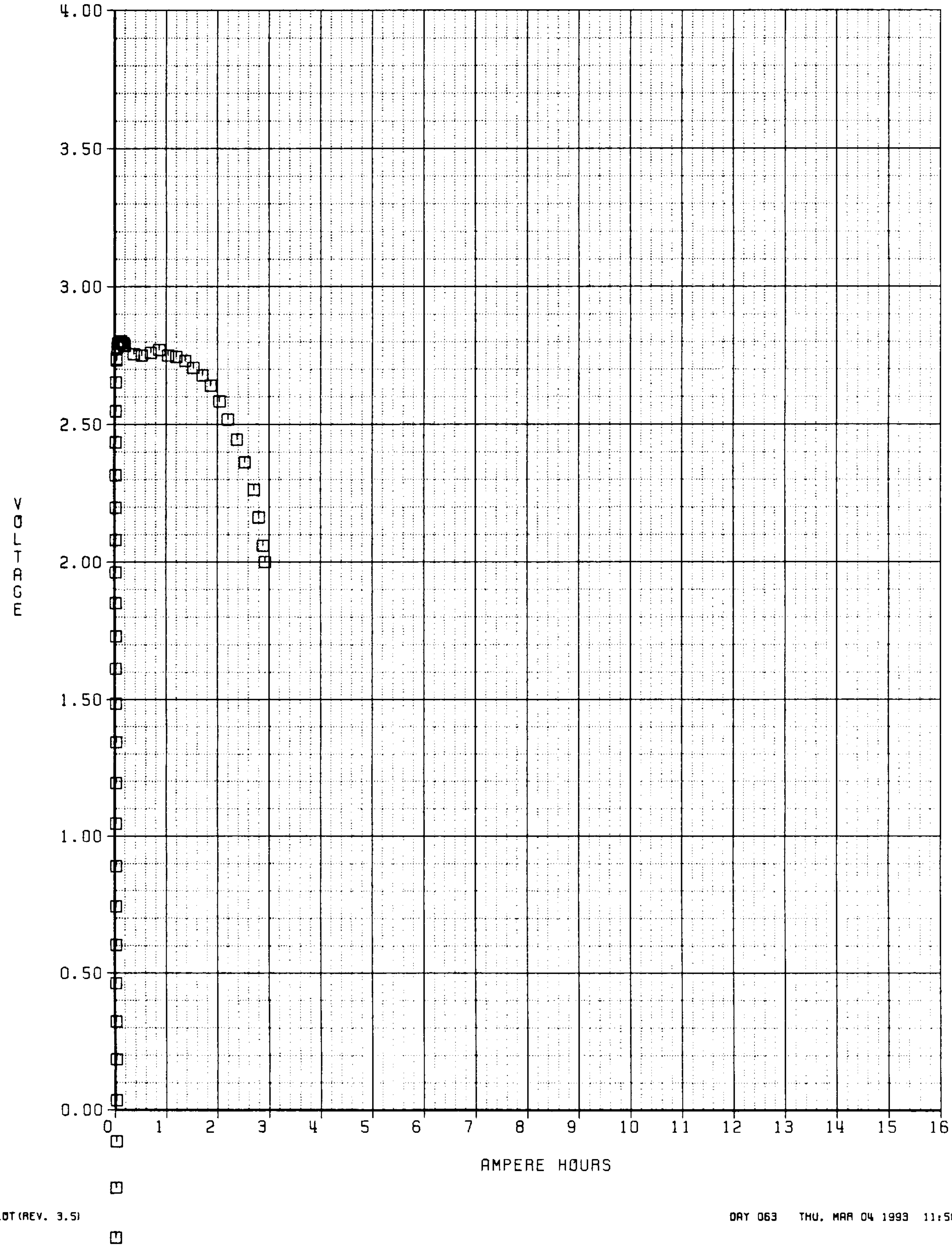
DAY 063 THU, MAR 04 1993 11:53:40 AM

Figure 38

NASA 1.2M LAC TC D CELL

FRESH/1 AMP DISCHARGE AT -25ºC

MACCOR3 ID 0555 OF NASA D CELL STUDY



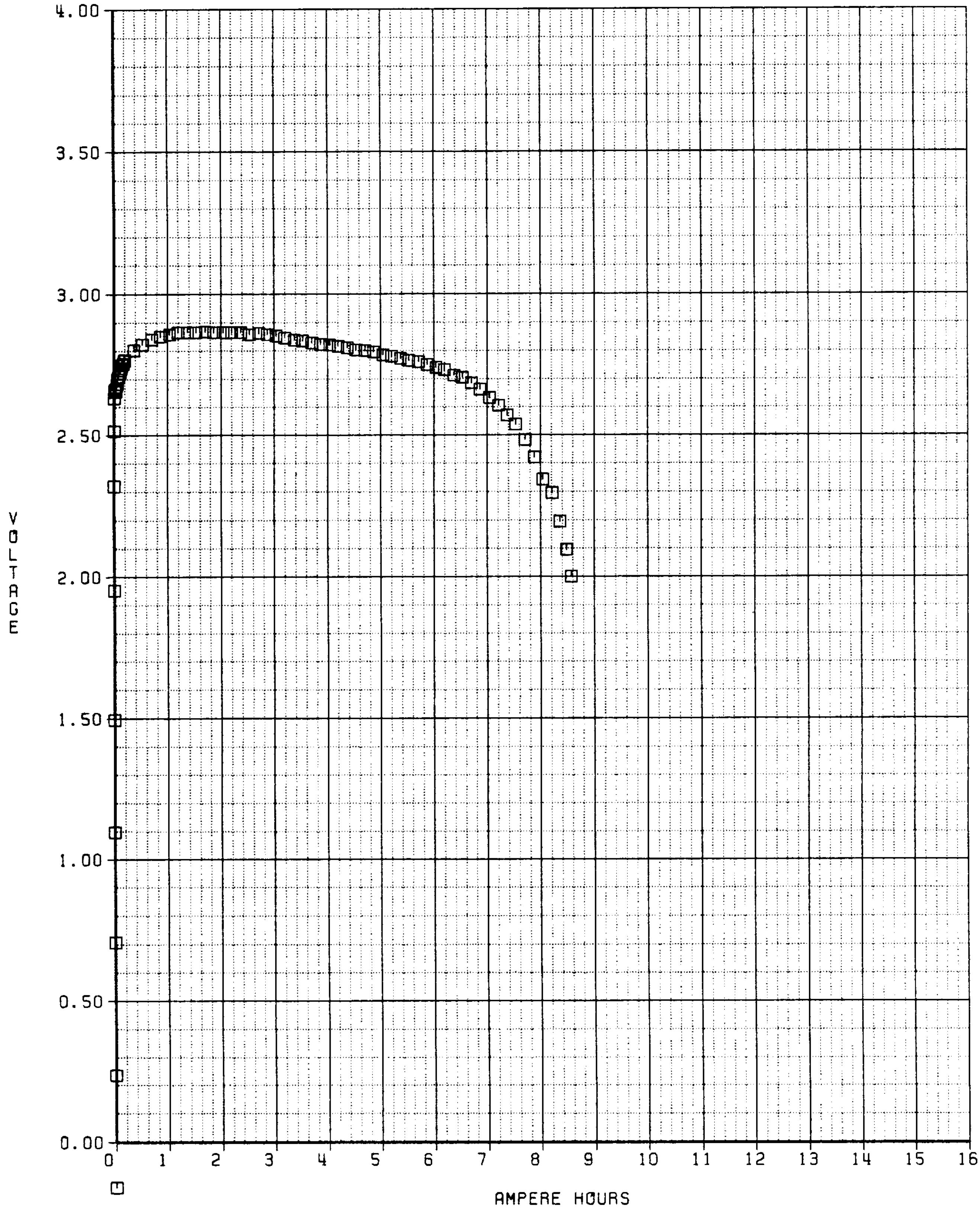
GPLOT(REV. 3.5)

DAY 063 THU. MAR 04 1993 11:50:14 AM

Figure 39

NASA 1.8M LAC CSC D CELL
FRESH/1 AMP DISCHARGE AT -25°C

MACCOR3 ID 0559 OF NASA D CELL STUDY



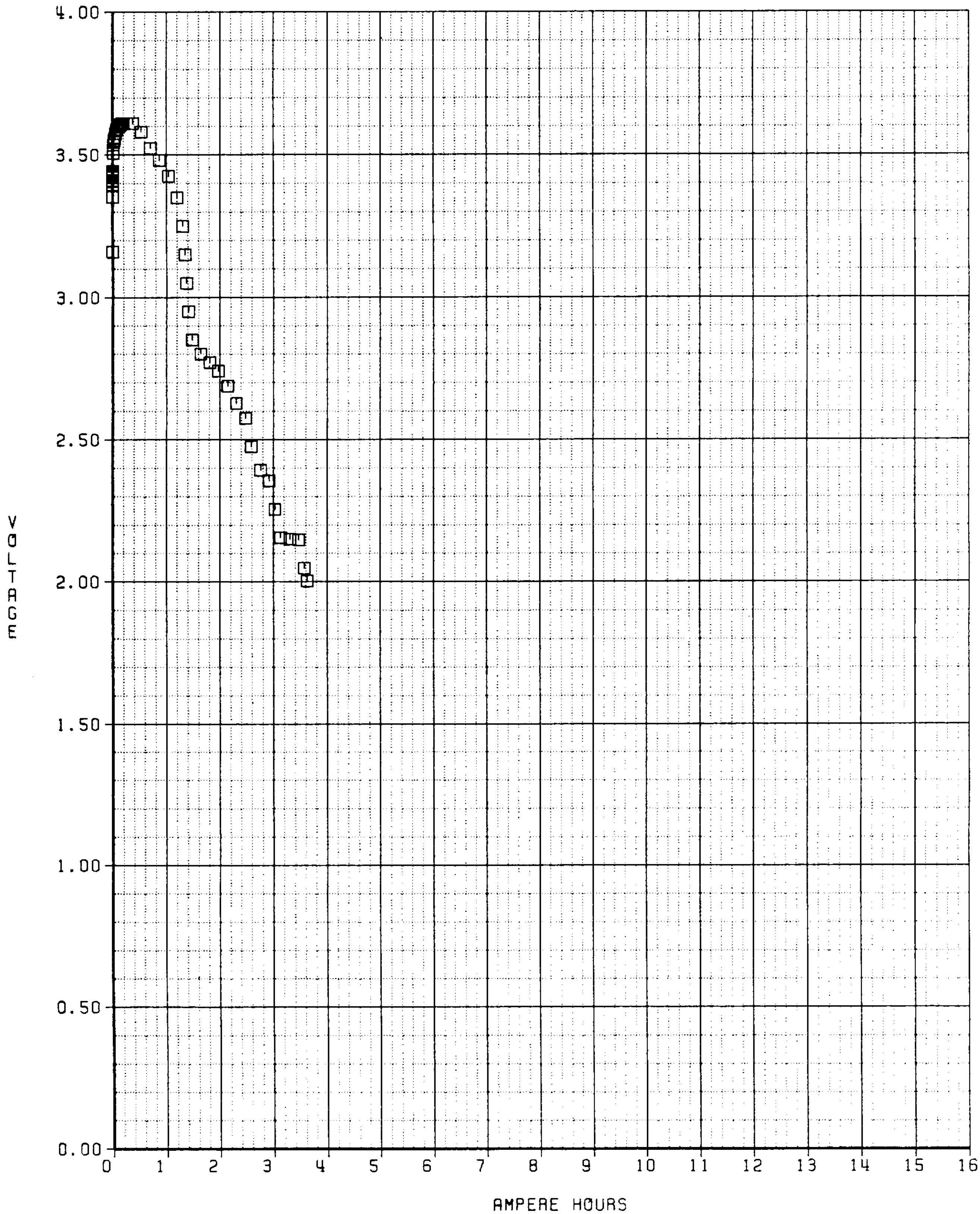
GPLOT (REV. 3.5)

DAY 063 THU, MAR 04 1993 11:44:44 AM

Figure 40

UNIV 0.6M LAC BCX D CELL
FRESH/1 AMP DISCHARGE AT -25°C

MACCOR3 ID 0562 OF NASA D CELL STUDY

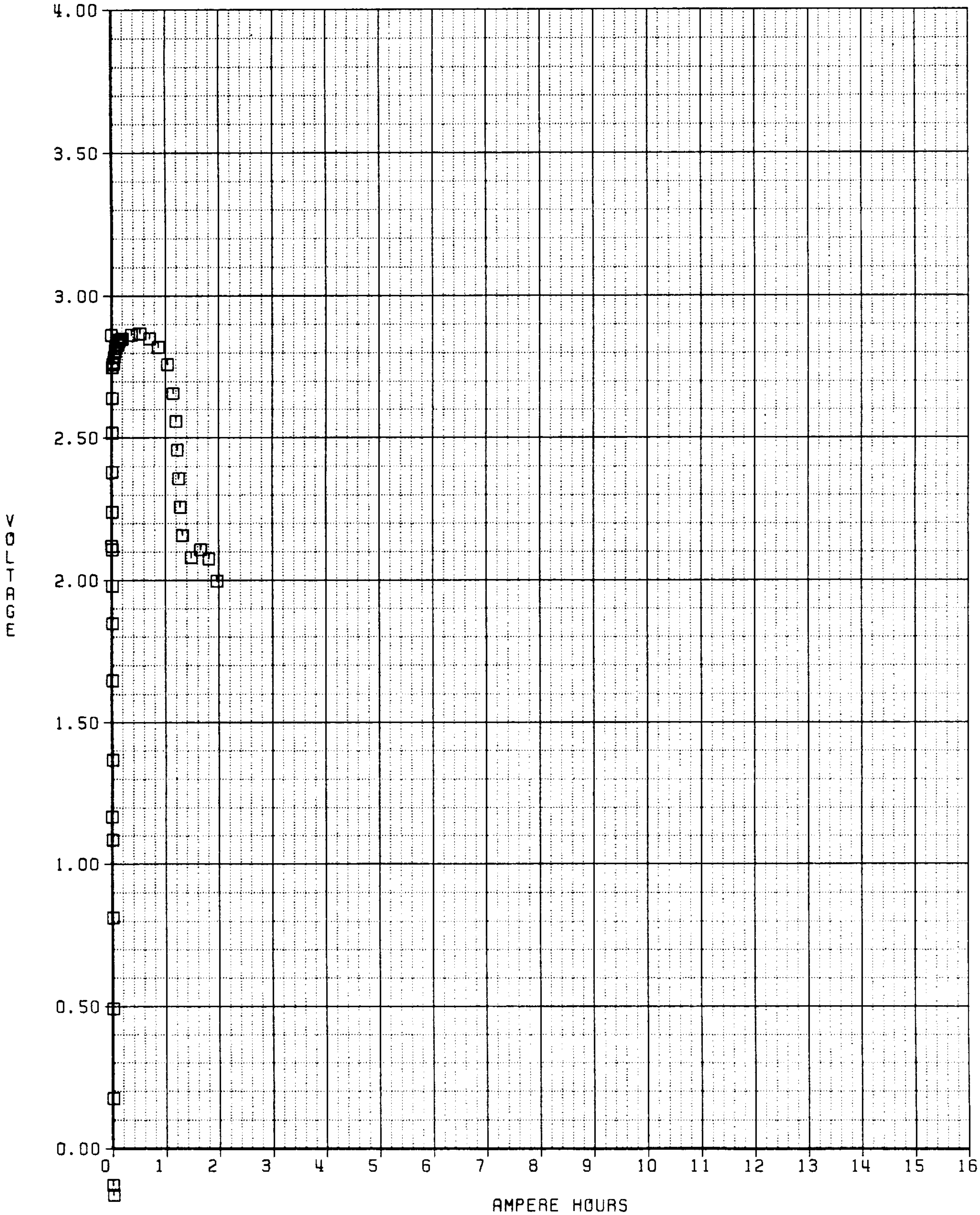


GPLOT(REV. 3.5) DAY 068 TUE. MAR 09 1993 12:47:09 PM

Figure 41

UNIV 1.2M LAC TC D CELL
FRESH/1 AMP DISCHARGE AT -25°C

MACCOR3 ID 0563 OF NASA D CELL STUDY



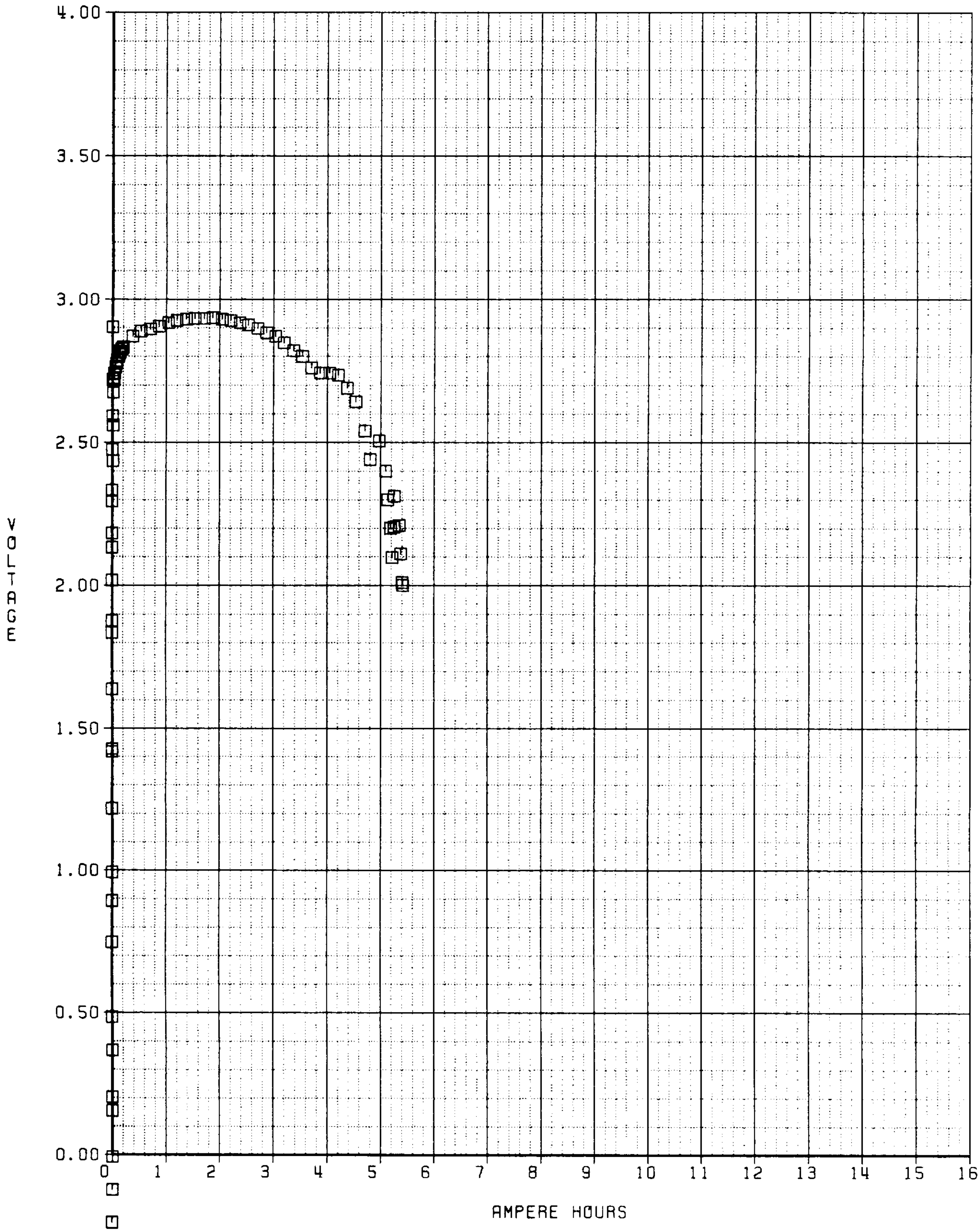
GPLOT(REV. 3.5)

DAY 063 THU, MAR 04 1993 11:23:44 AM

Figure 42

UNIV 1.8M LAC CSC D CELL
FRESH/1 AMP DISCHARGE AT -25ºC

MACCOR3 ID 0567 OF NASA D CELL STUDY



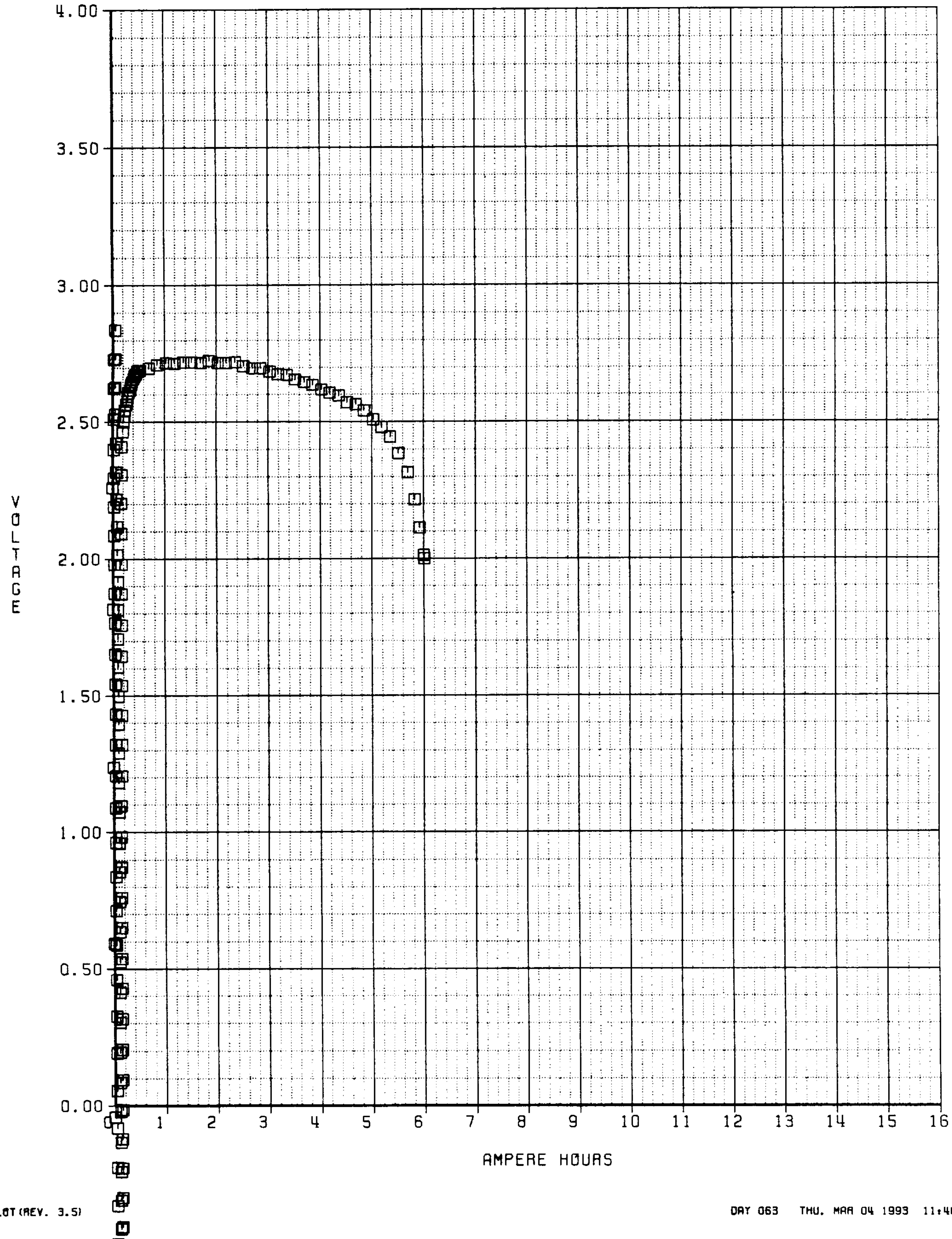
GPLOT (REV. 3.5)

DAY 063 THU, MAR 04 1993 11:20:51 AM

Figure 43

JPL 1.2M LAC BCX D CELL
FRESH/1 AMP DISCHARGE AT -25°C

MACCOR3 ID 0570R OF NASA D CELL STUDY



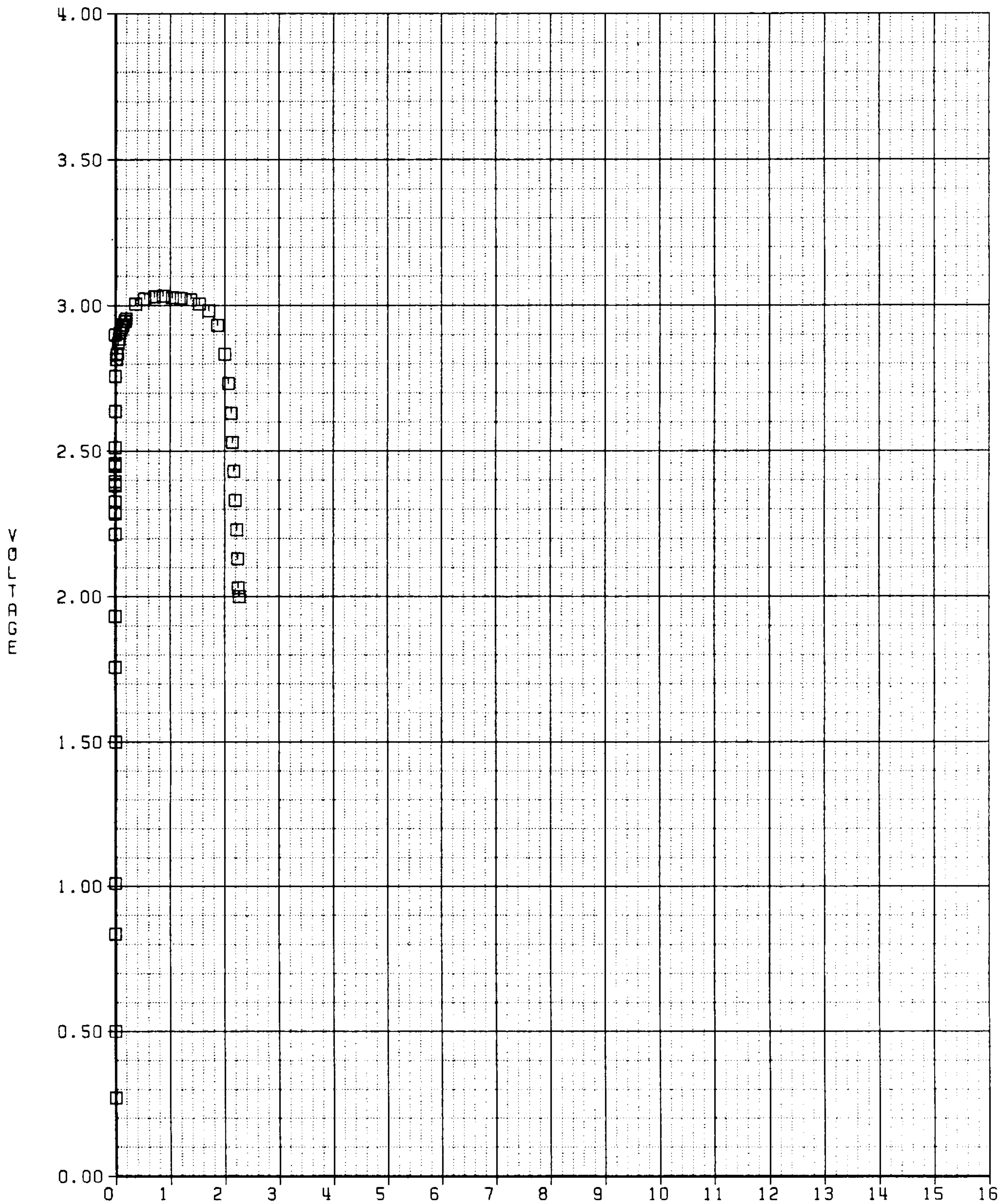
GPLOT (REV. 3.5)

DAY 063 THU. MAR 04 1993 11:40:36 AM

Figure 44

JPL 1.8M LAC TC D CELL
FRESH/1 AMP DISCHARGE AT $-25^{0}C$

MACCOR3 ID 0572 OF NASA D CELL STUDY



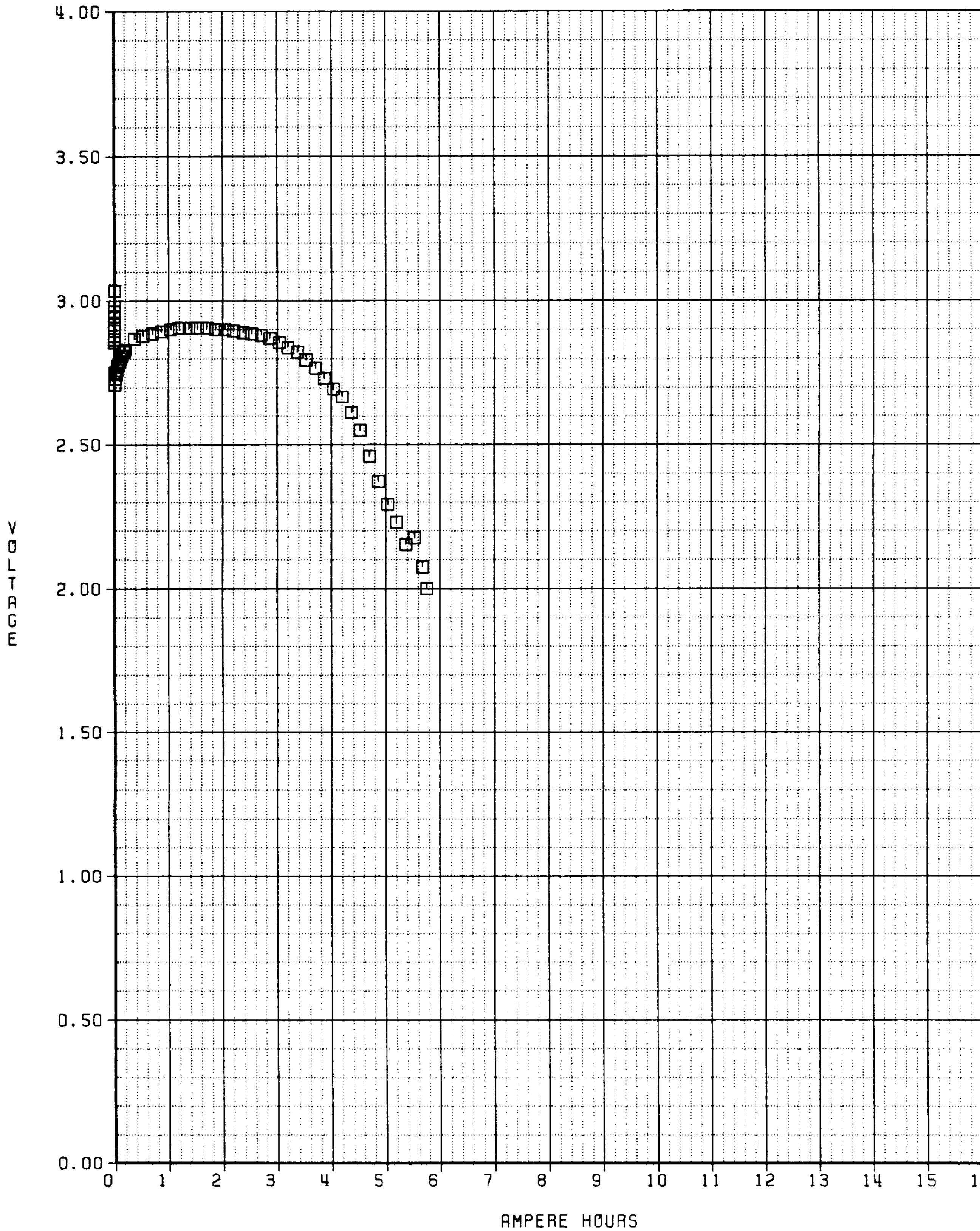
GPLOT(REV. 3.5)

DAY 063 THU. MAR 04 1993 11:36:58 AM

Figure 45

JPL 0.6M LAC CSC D CELL
FRESH/1 AMP DISCHARGE AT -25^{0}C

MACCOR3 ID 0577 OF NASA D CELL STUDY



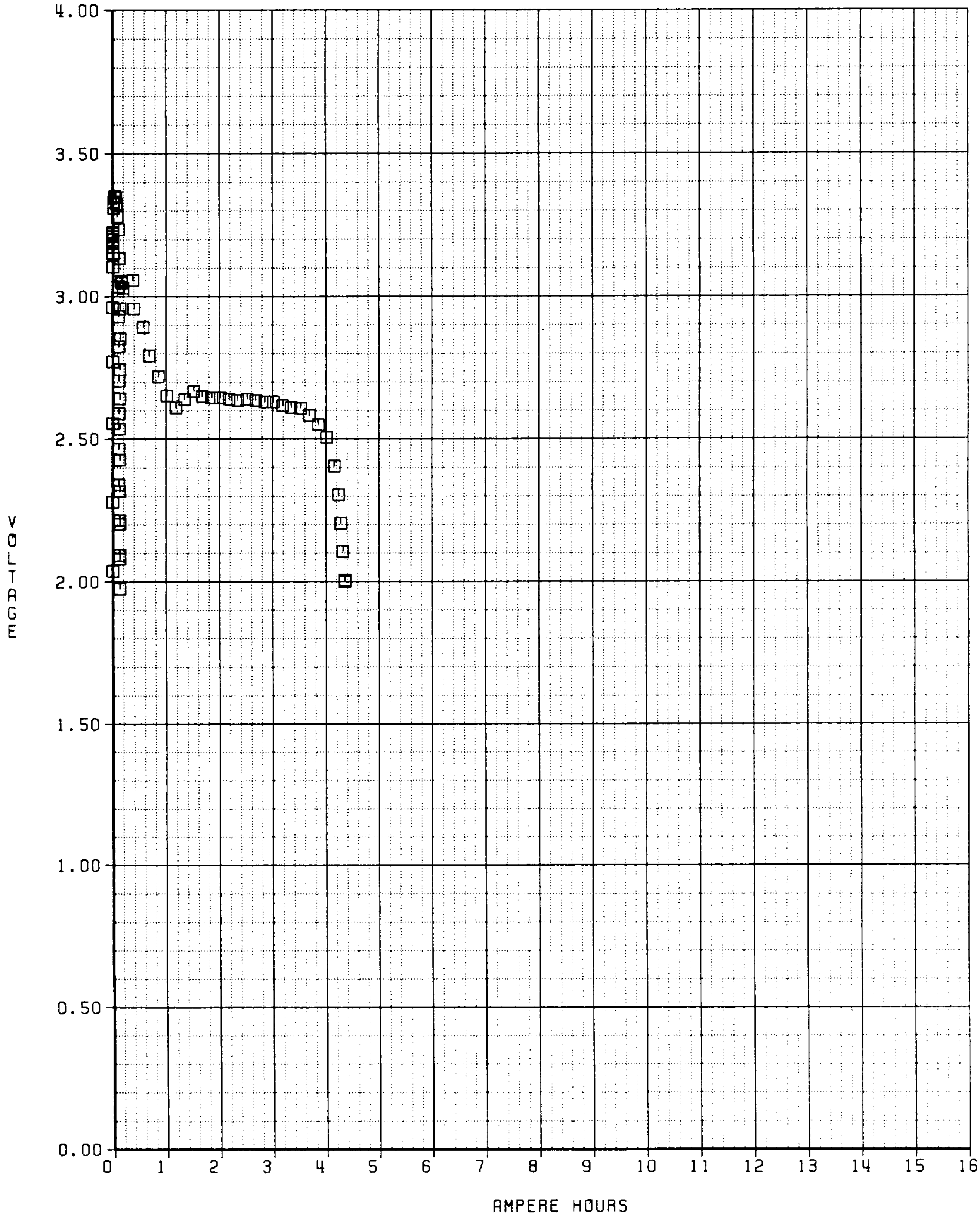
GPLOT(REV. 3.5)

DAY 063 THU. MAR 04 1993 11:32:49 AM

Figure 46

NASA 1.8M LGC BCX D CELL
FRESH/1 AMP DISCHARGE AT -25°C

MACCOR3 ID 0578 OF NASA D CELL STUDY



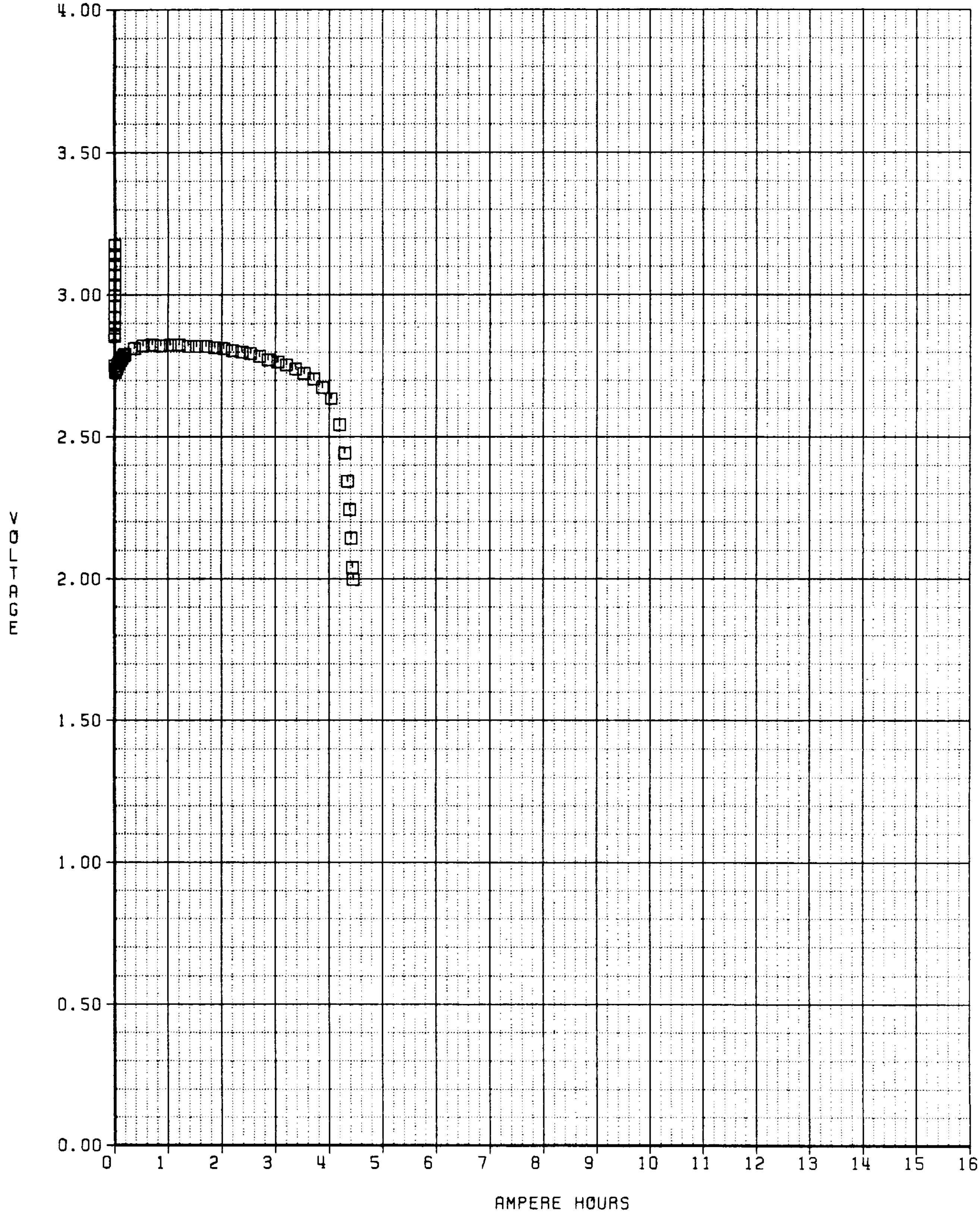
GPLOT(REV. 3.5)

DAY 062 WED, MAR 03 1993 3:40:52 PM

Figure 47

NASA 0.6M LGC TC D CELL
FRESH/1 AMP DISCHARGE AT -25^{0}C

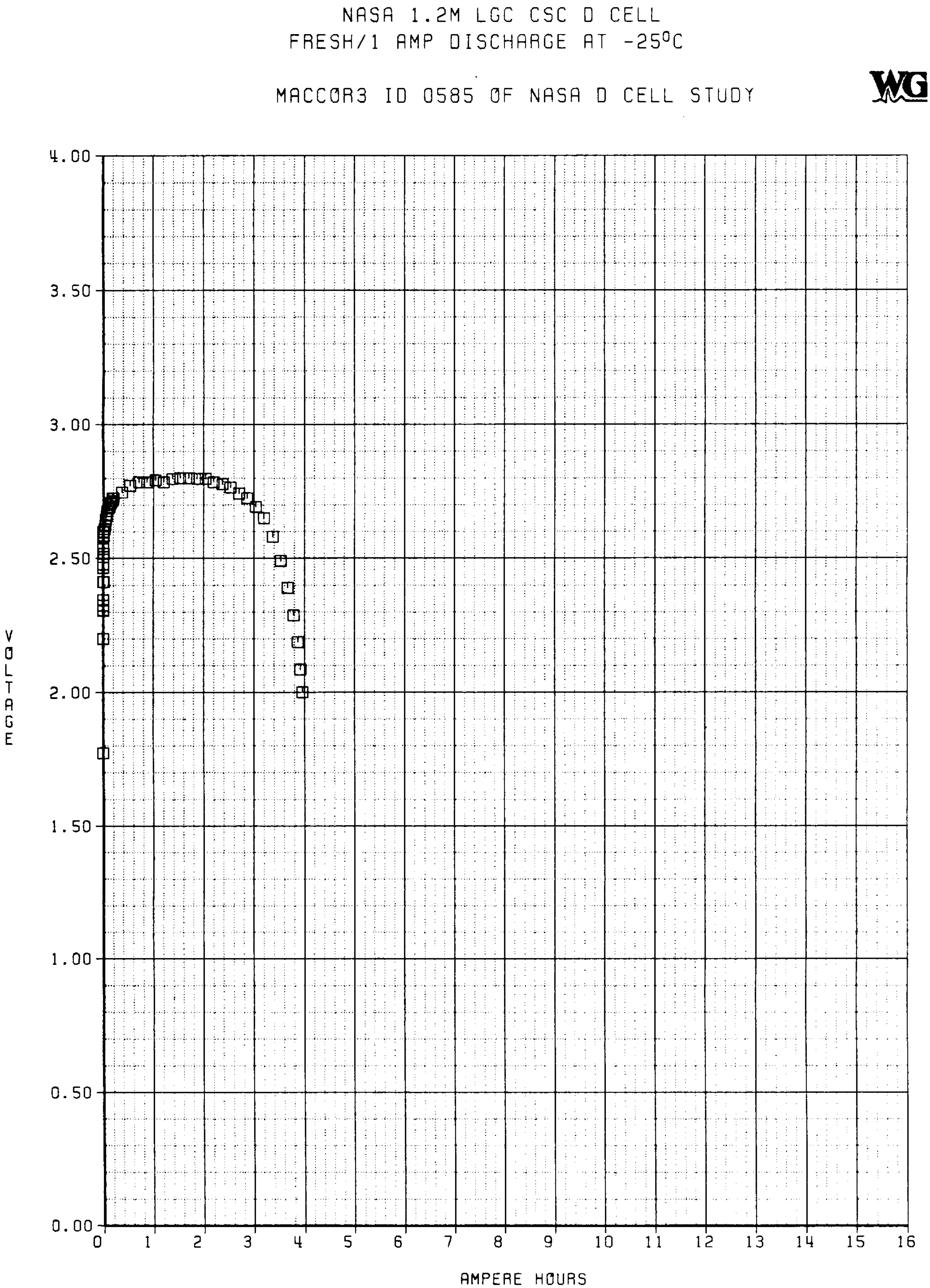
MACCOR3 ID 0581 OF NASA D CELL STUDY



GPLOT(REV. 3.5)

DAY 062 WED, MAR 03 1993 3:36:56 PM

Figure 48



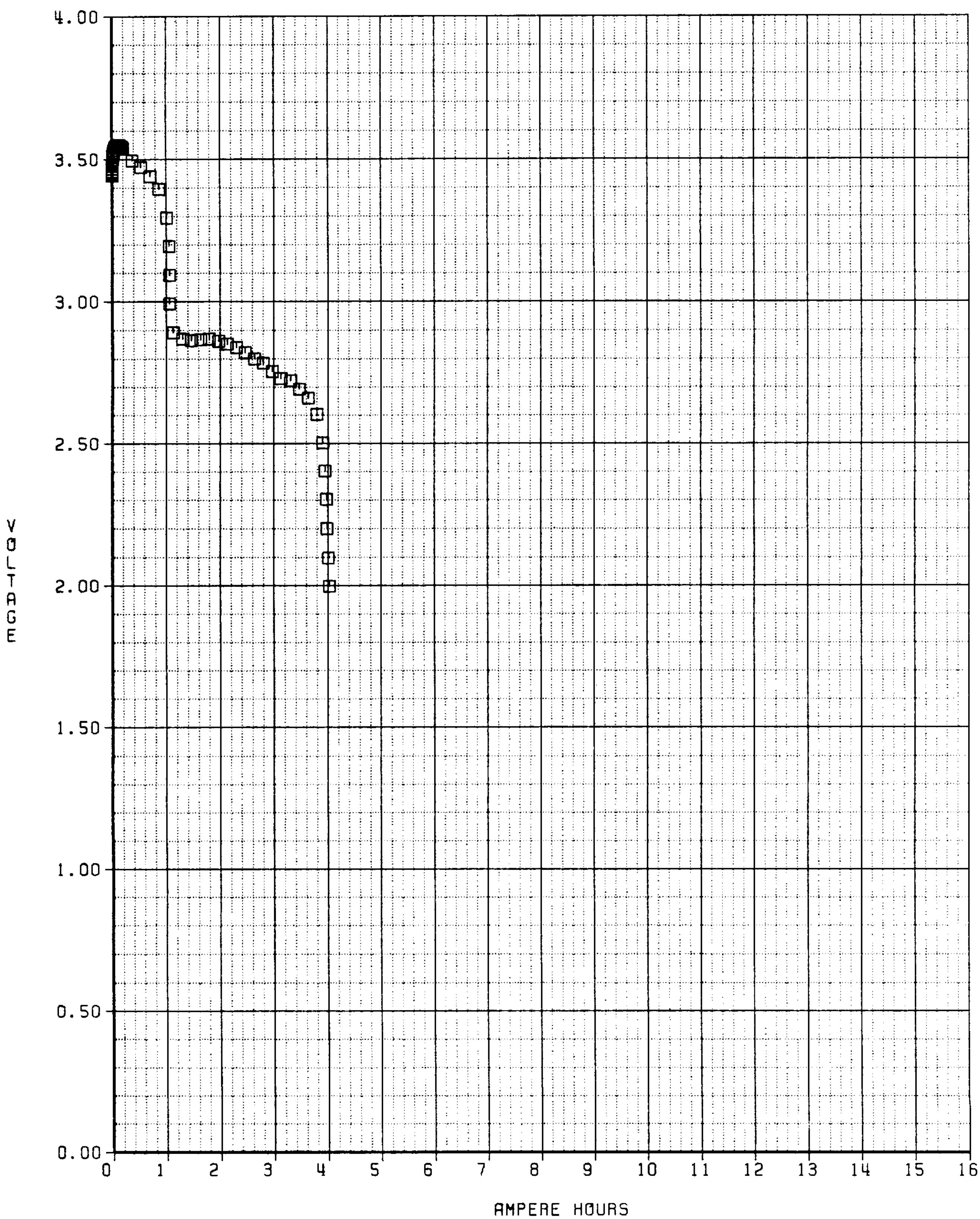
GPLOT(REV. 3.5)

DAY 062 WED. MAR 03 1993 3:43:54 PM

Figure 49

UNIC 1.2M LGC BCX D CELL
FRESH/1 AMP DISCHARGE AT -25°C

MACCOR3 ID 0587 OF NASA D CELL STUDY

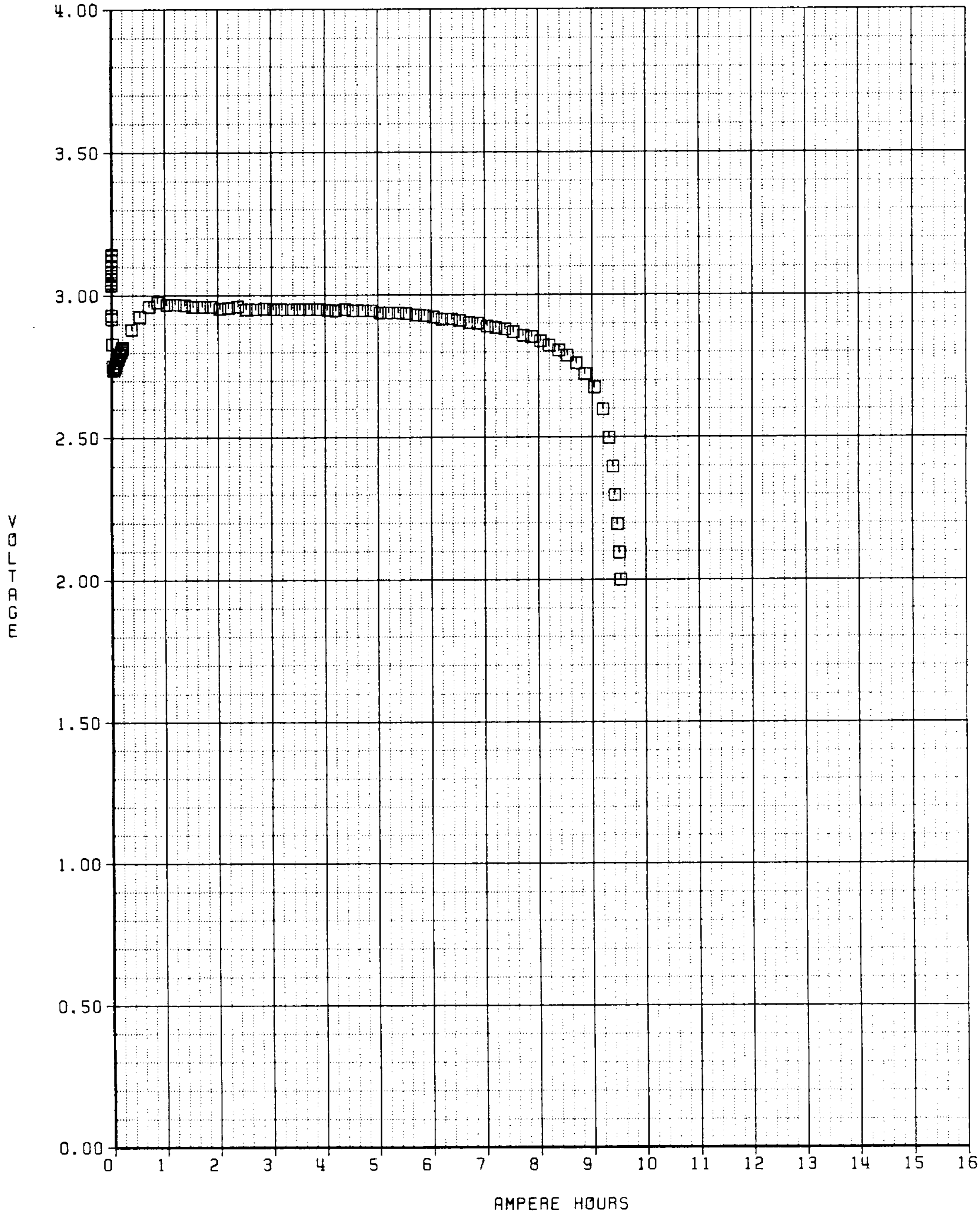


GPLOT (REV. 3.5) DAY 063 THU. MAR 04 1993 11:09:56 AM

Figure 50

UNIC 1.8M LGC TC D CELL
FRESH/1 AMP DISCHARGE AT -25^{0}C

MACCOR3 ID 0591 OF NASA D CELL STUDY



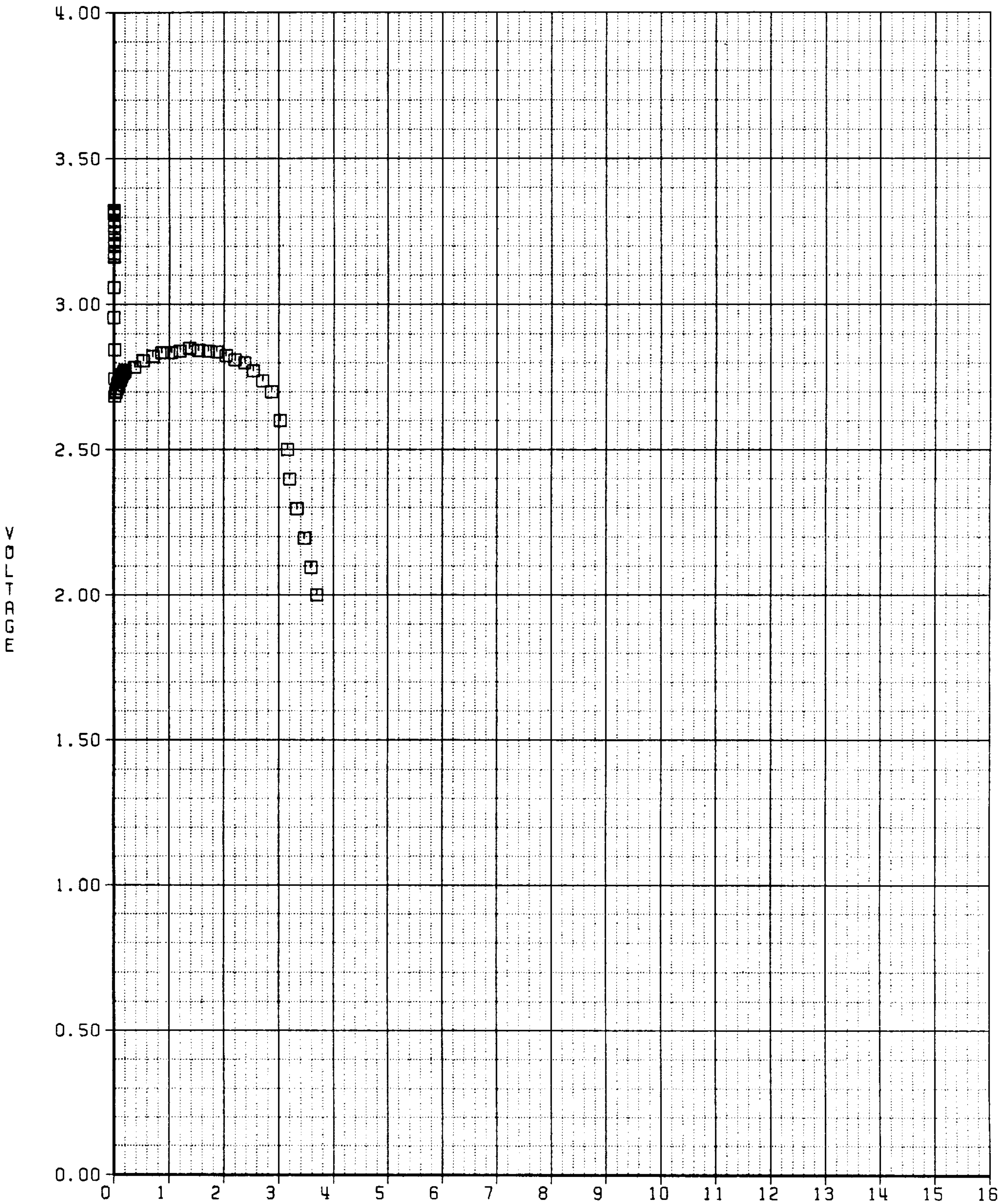
GPLOT (REV. 3.5)

DAY 063 THU, MAR 04 1993 11:12:31 AM

Figure 51

UNIC 0.6M LGC CSC D CELL
FRESH/1 AMP DISCHARGE AT -25°C

MACCOR3 ID 0595 OF NASA D CELL STUDY

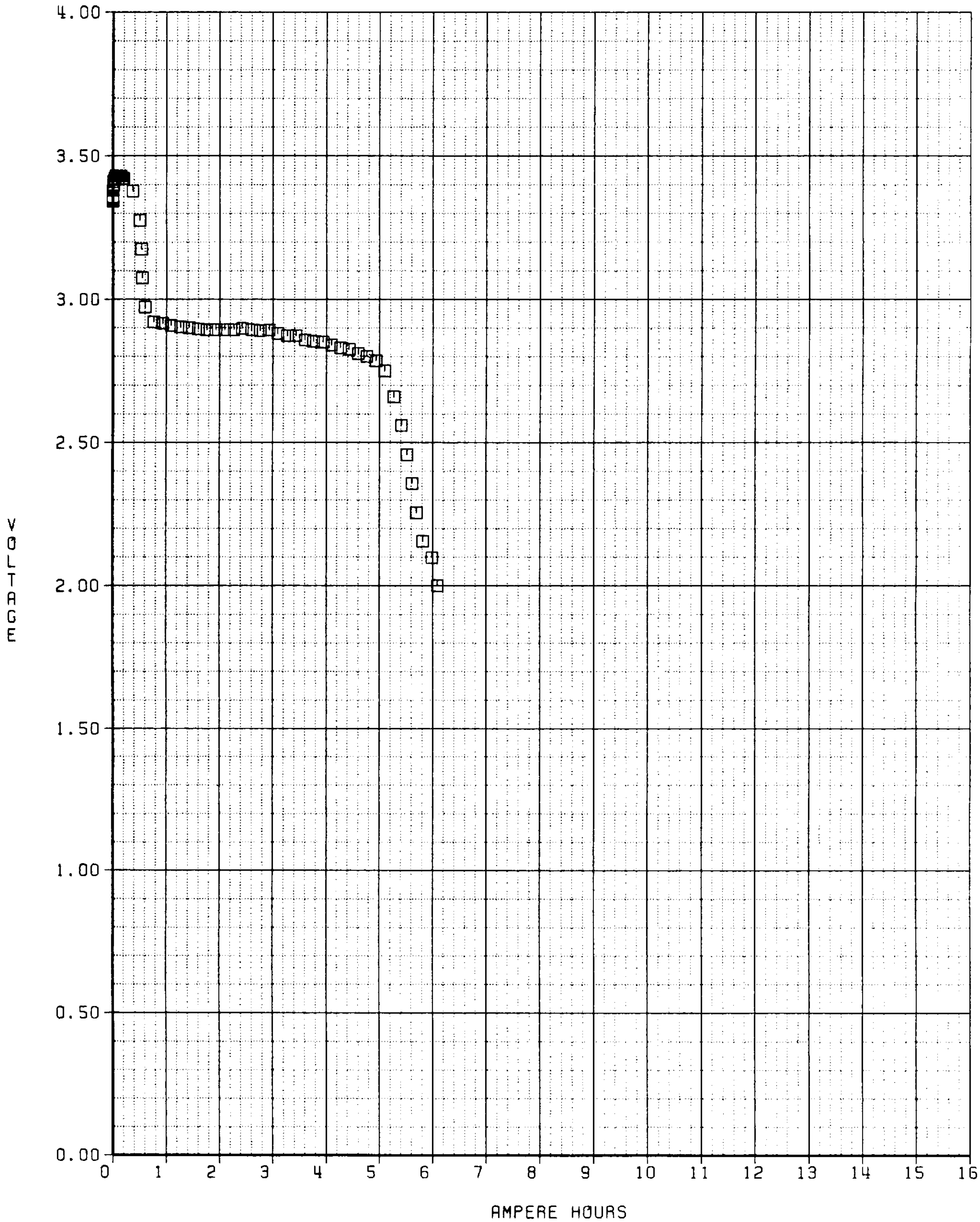


GPLOT(REV. 3.5) DAY 063 THU, MAR 04 1993 11:16:16 AM

Figure 52

JPL 1.8M LGC BCX D CELL
FRESH/1 AMP DISCHARGE AT -25°C

MACCOR3 ID 0597 OF NASA D CELL STUDY

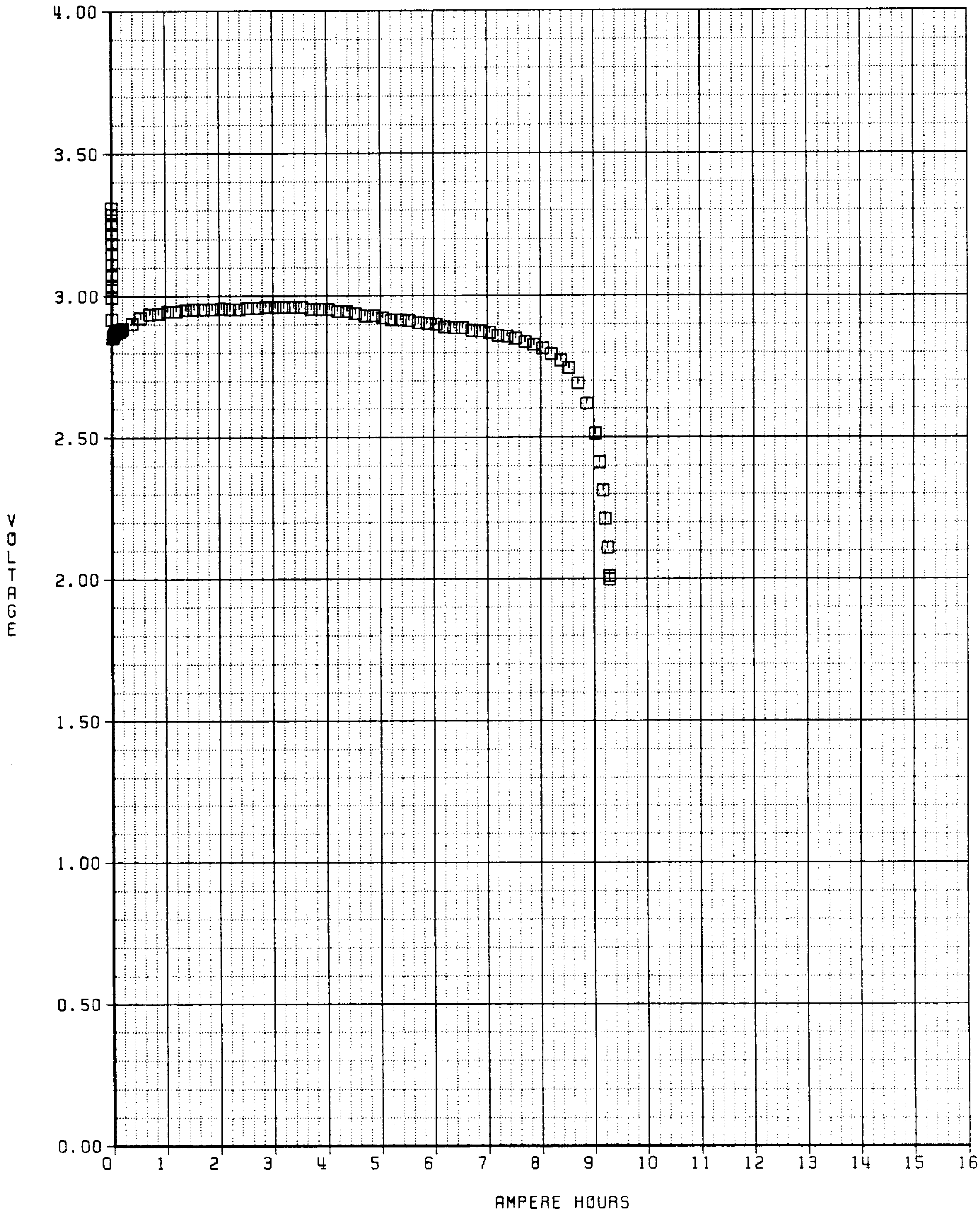


GPLOT (REV. 3.5)   DAY 063 THU, MAR 04 1993 11:06:03 AM

Figure 53

JPL 0.6M LGC TC D CELL
FRESH/1 AMP DISCHARGE AT -25^{0}C

MACCOR3 ID 0600 OF NASA D CELL STUDY

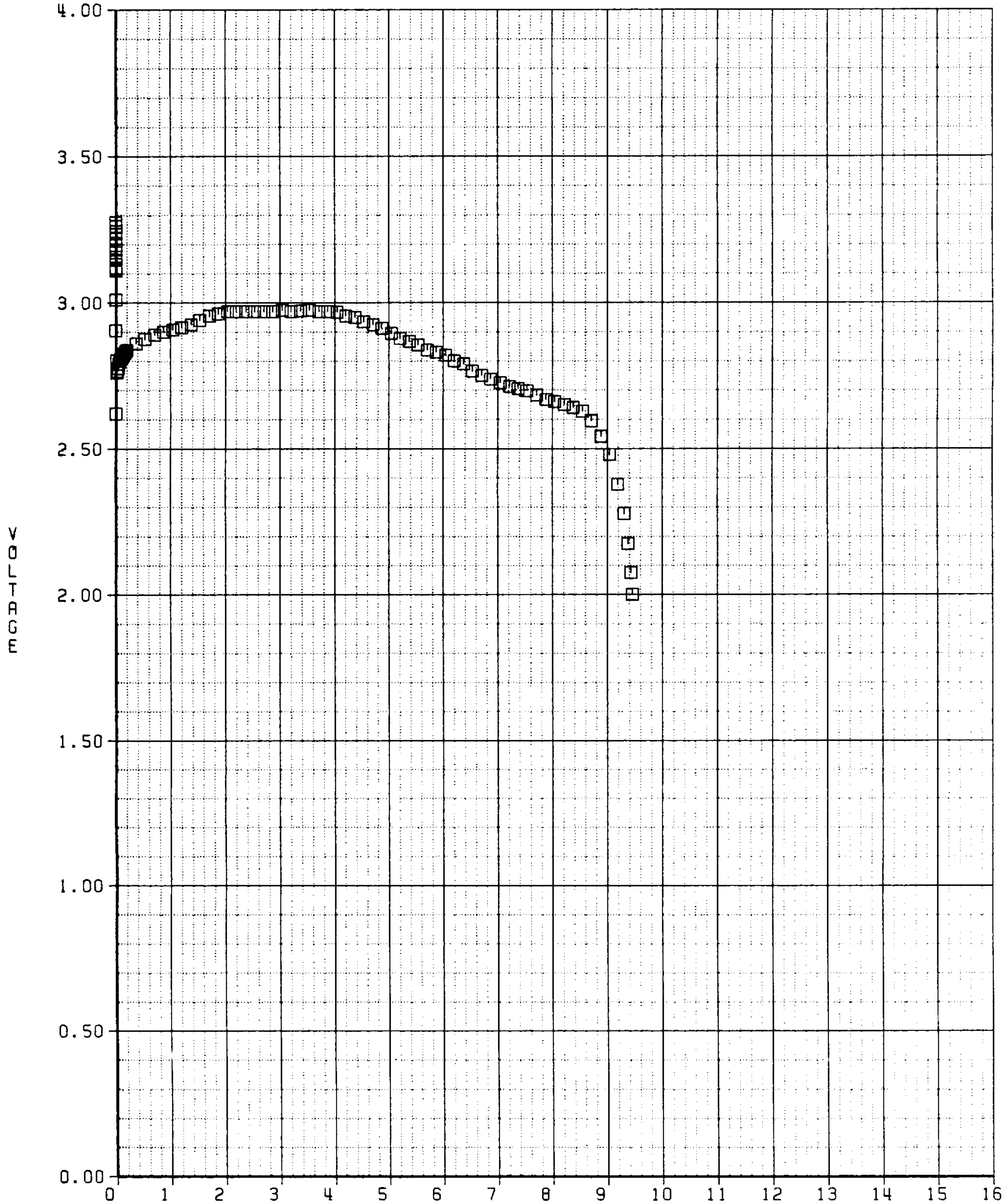


GPLOT (REV. 3.5) DAY 063 THU, MAR 04 1993 11:03:12 AM

Figure 54

JPL 1.2M LGC CSC D CELL
FRESH/1 AMP DISCHARGE AT -25°C

MACCOR3 ID 0604 OF NASA D CELL STUDY



GPLOT (REV. 3.5)

DAY 063 THU, MAR 04 1993 11:00:16 AM

Figure 55

Effect of electrolyte salt on voltage delay of D cells discharged at 3A under room temperature conditions.

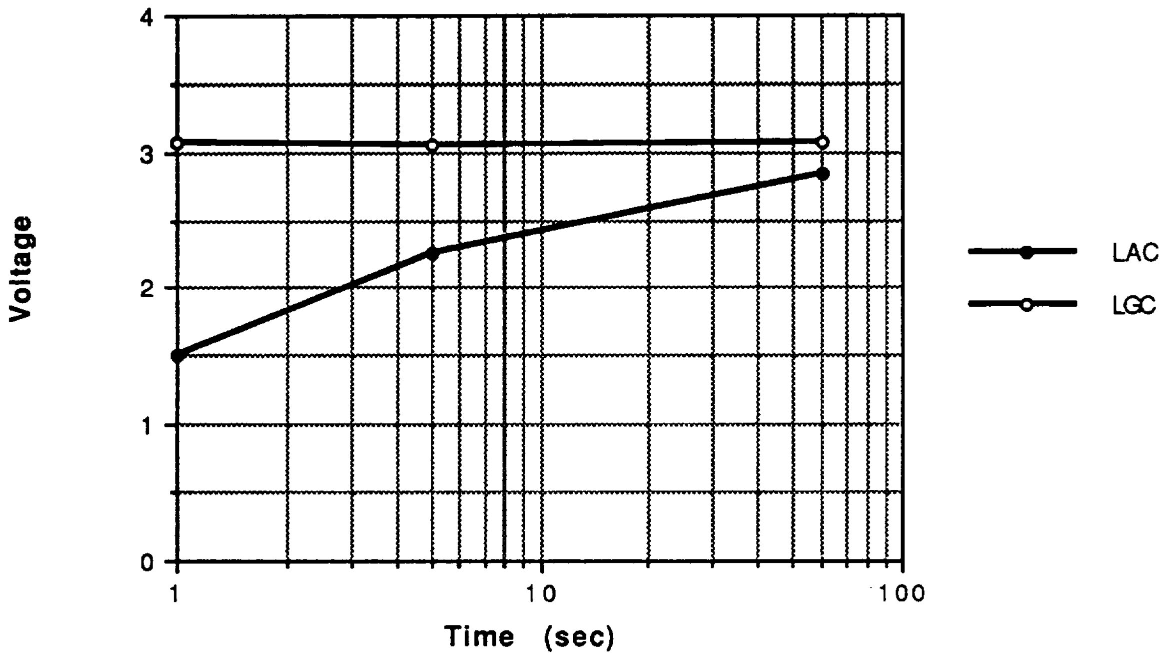


Figure 56

Effect of depolarizer on voltage delay of D cells discharged at 3A under room temperature conditions.

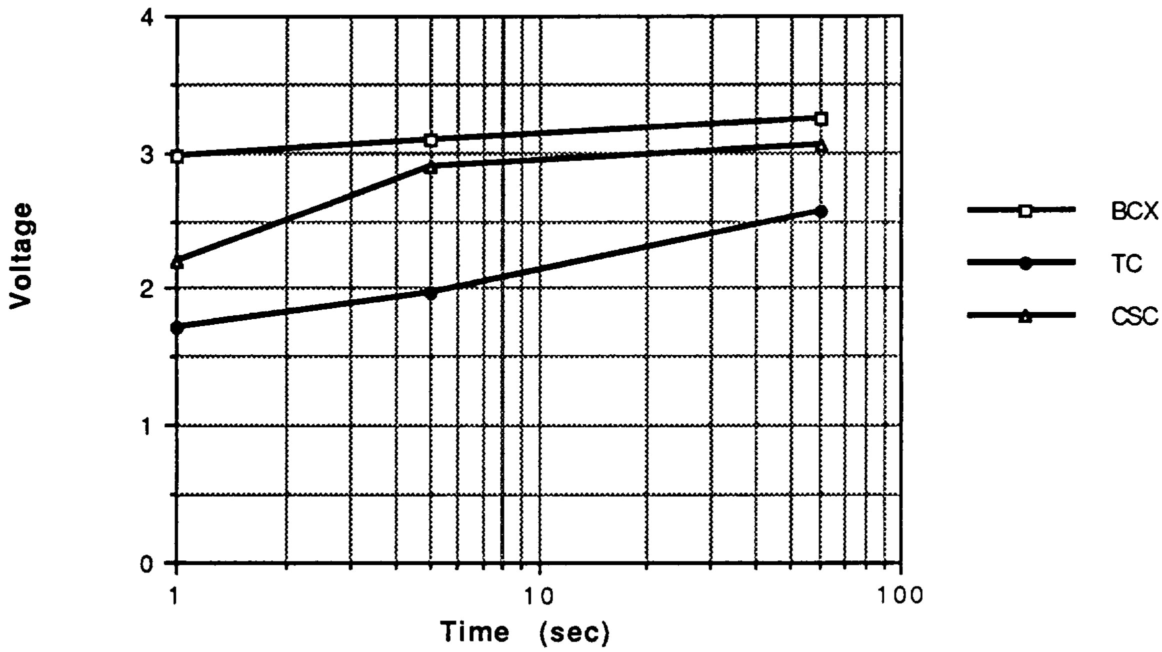
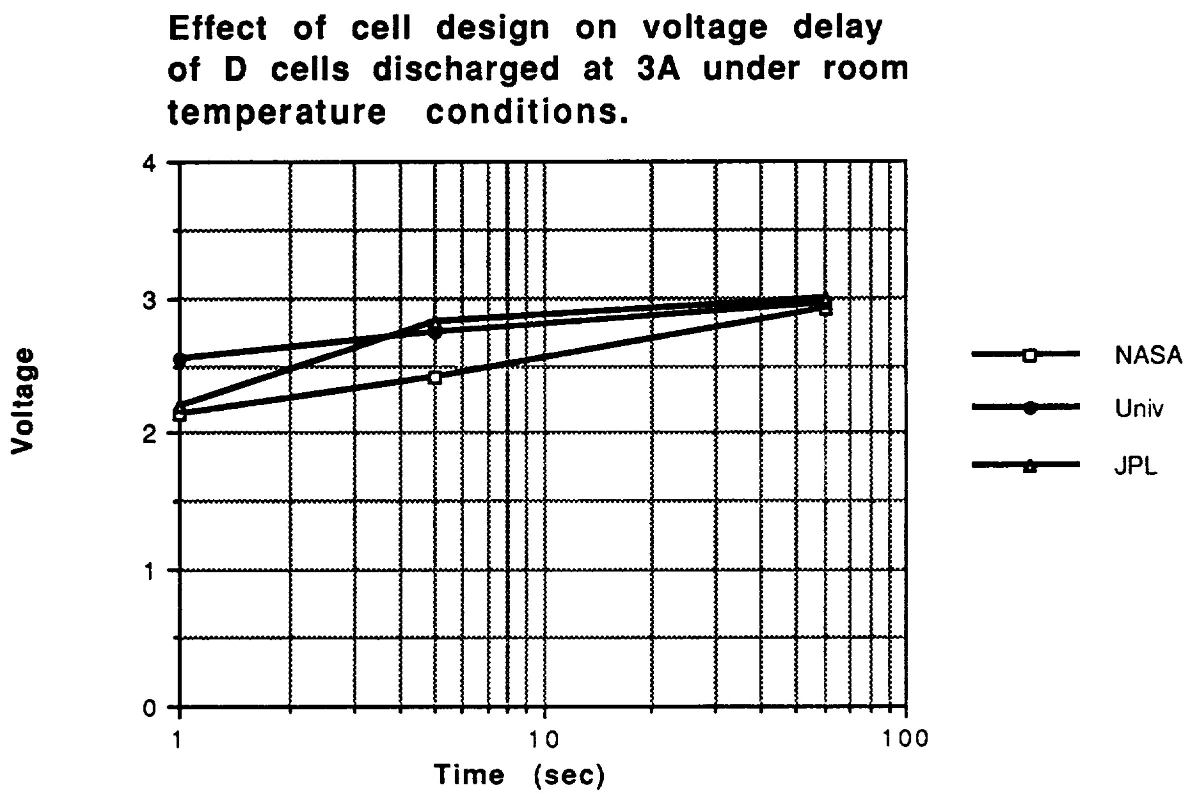


Figure 57



Effect of cell design on voltage delay of D cells discharged at 3A under room temperature conditions.
Voltage
4
3
2
1
0
1
10
100
Time (sec)
NASA
Univ
JPL

Figure 58

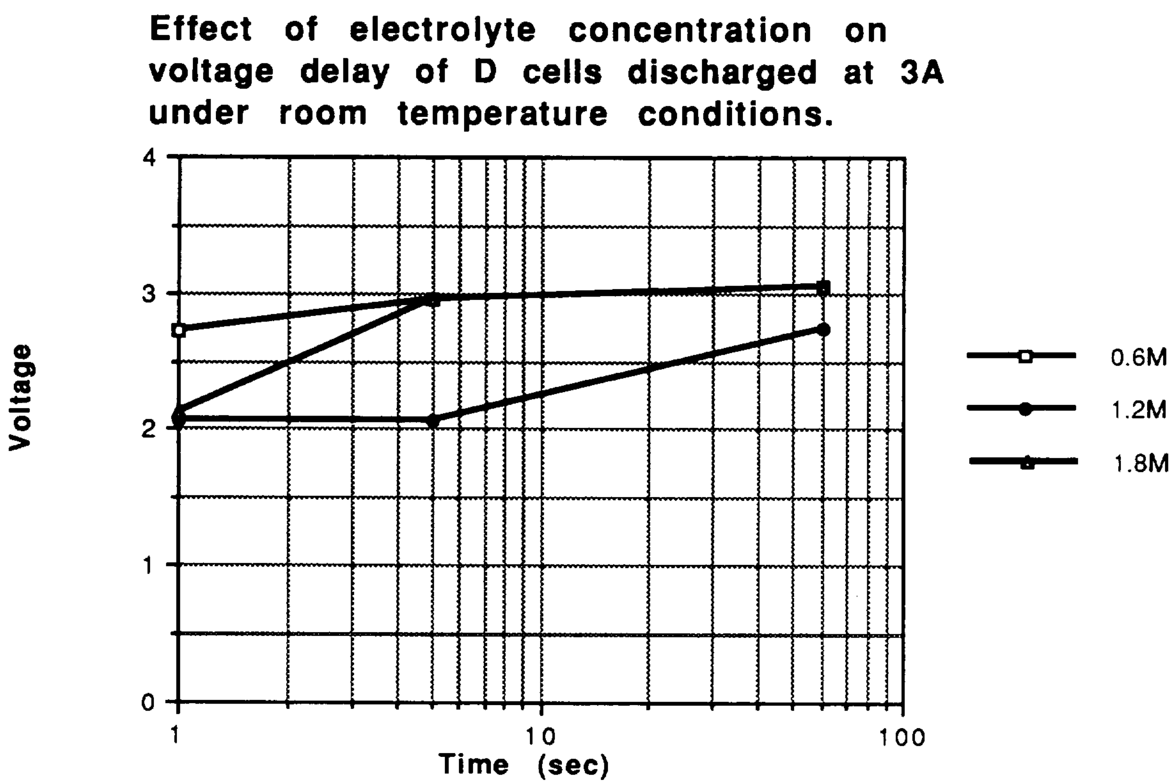

Effect of electrolyte concentration on voltage delay of D cells discharged at 3A under room temperature conditions.
Voltage
4
3
2
1
0
1
10
100
Time (sec)
0.6M
1.2M
1.8M

Figure 59

Effect of depolarizer on running voltage of fresh cells discharged at 3A under room temperature conditions.

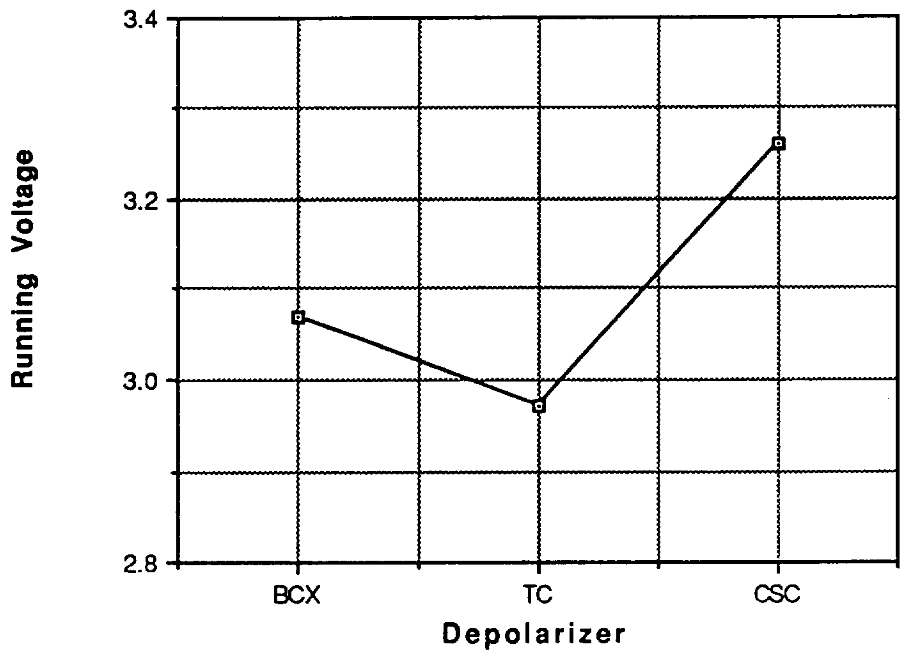


Figure 60

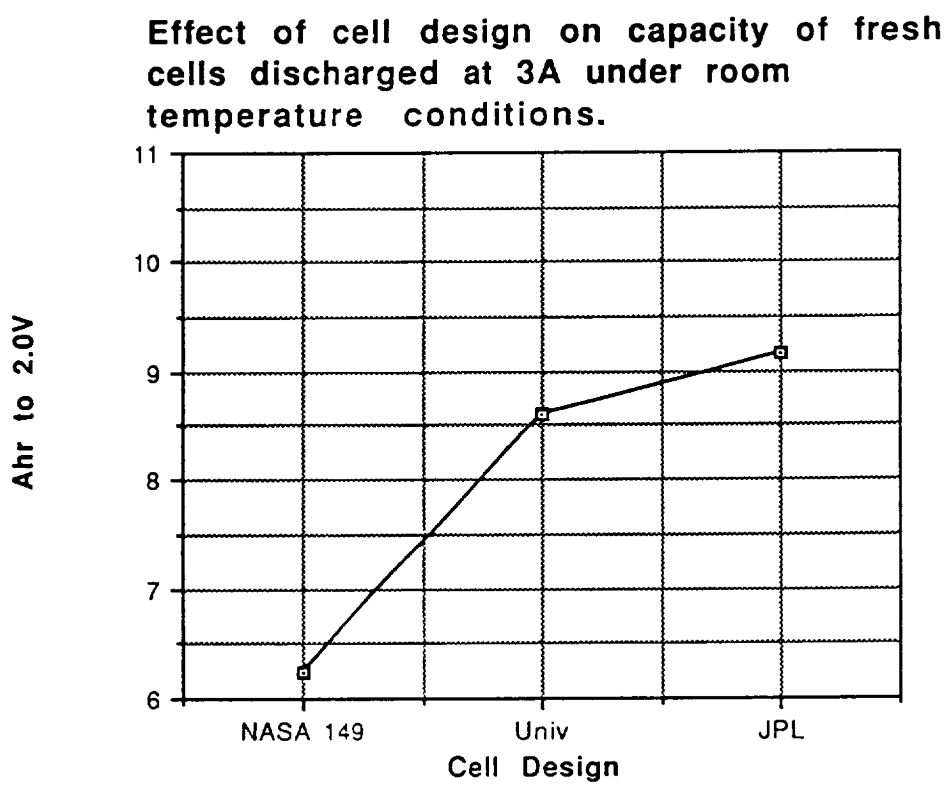

Effect of cell design on capacity of fresh cells discharged at 3A under room temperature conditions.
Ahr to 2.0V
11
10
9
8
7
6
NASA 149
Univ
JPL
Cell Design

Figure 61

Effect of depolarizer on capacity of fresh cells discharged at 3A under room temperature conditions.

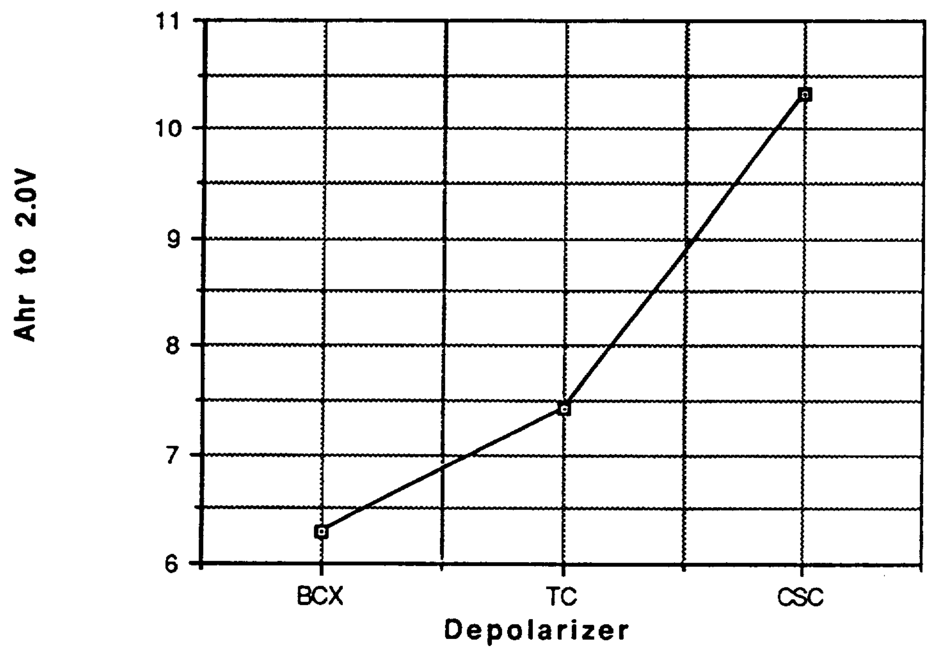
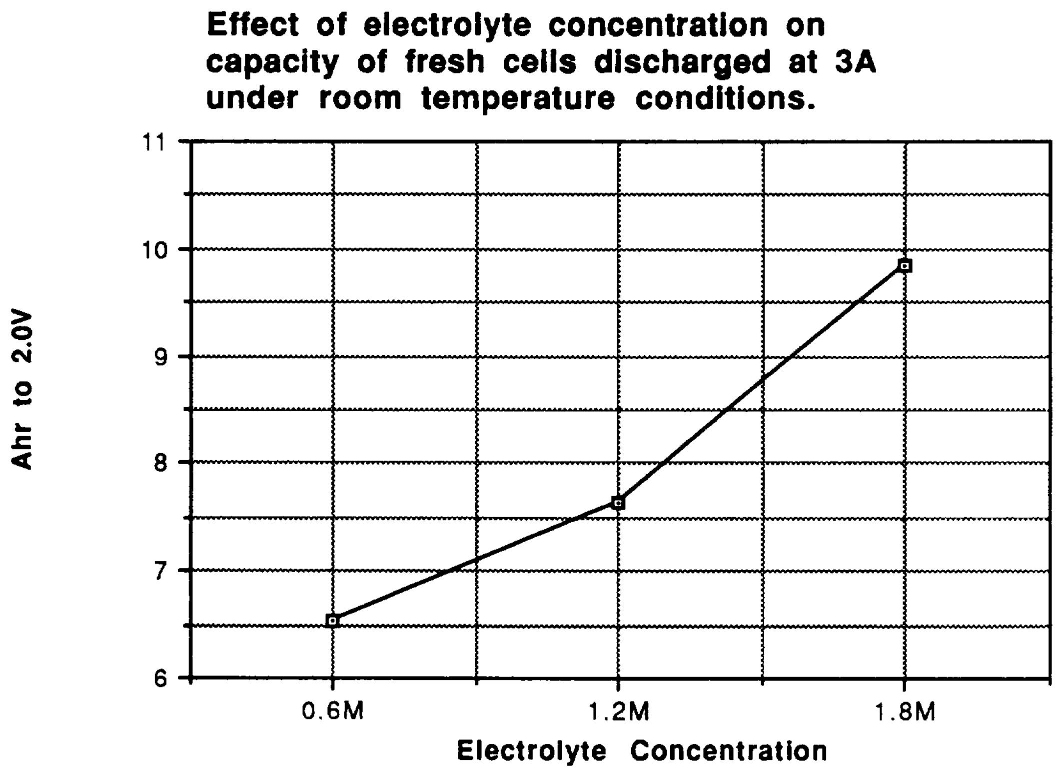


Figure 62


Effect of electrolyte concentration on capacity of fresh cells discharged at 3A under room temperature conditions.
Ahr to 2.0V
11
10
9
8
7
6
0.6M
1.2M
1.8M
Electrolyte Concentration

The ANOVA reports for the five performance attributes are located in Appendix D, and representaive discharge curves are found in figures 63 - 80.

5.4 FRESH 3A, -25°C PERFORMANCE

Figures 81 - 84 illustrate the effects of the four factors on voltage delay in D cells discharged at 3A and -25°C. The factor having the largest effect on initial start up voltage is the electrolyte type, which contributes 53.5% to the variation in performance. This is mainly due to the fact that 17 of 27 cells containing the LAC electrolyte failed to start up within 1 second and 6 cells were at zero volts after 60 seconds. The average starting voltage for cells with the LGC electrolyte was 2.67V compared to 0.83V for cells with LAC electrolyte. By the end of the 60 second start up test the contribution of electrolyte to performance variation was 14.5% with cells containing LGC electrolyte running 790 millivolts higher than cells with LAC electrolyte. The cell design contributed 0.1 - 5.2% to the voltage variation over the course of the 60 second test, and the depolarizer contributed 5 - 15%. Figure 64 shows that cells with BCX depolarizer had better start up characteristics than the other two depolarizers. This is consistent with all four discharge conditions studied. The electrolyte concentration affects the voltage delay characteristics with a contribution of 15 - 22% to the variation of voltage. (See figure 84). The cells with the 0.6M electrolyte have better start up characteristics than the higher concentration electrolytes. This also is consistent with all test conditions.

As with the previous testing, the analysis of the running voltage at 50% DOD is subject to error. 81.6% of the variation in performance is due to outside factors. None of the factors played a significant role in determining the running voltage of D cells tested under these conditions.

The capacity of D cells discharged under these conditions was affected by all four factors to a similar degree. Cells with LGC electrolyte delivered higher capacities than cells with LAC electrolyte, and the type of salt used contributed 11.7% to the variation in performance. The JPL cells also delivered the highest capacities (6.11 Ah compared to 5.28 Ah for UNIV cells and 2.93 Ah for NASA cells), contributing 19.2% to variability. Cells with CSC depolarizer delivered the highest capacities of the three depolarizers, contributing 14.6%, and high molarity electrolyte delivered the highest capacities contributing 12.4% to variability. Refer to figures 85 - 88.

The ANOVA reports for this section of the contract are included in Appendix E. Seventeen representative discharge curves are

Figure 63

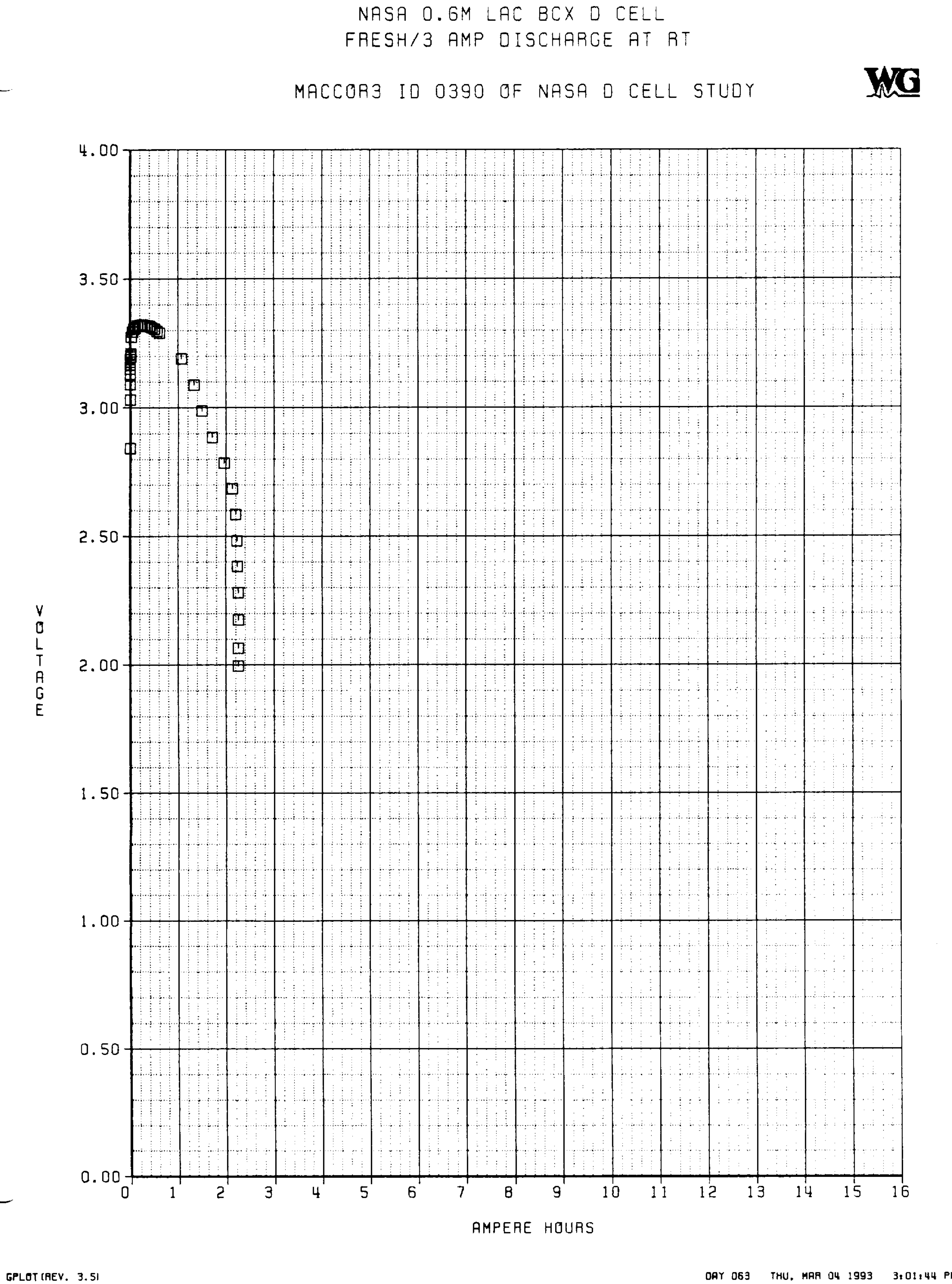
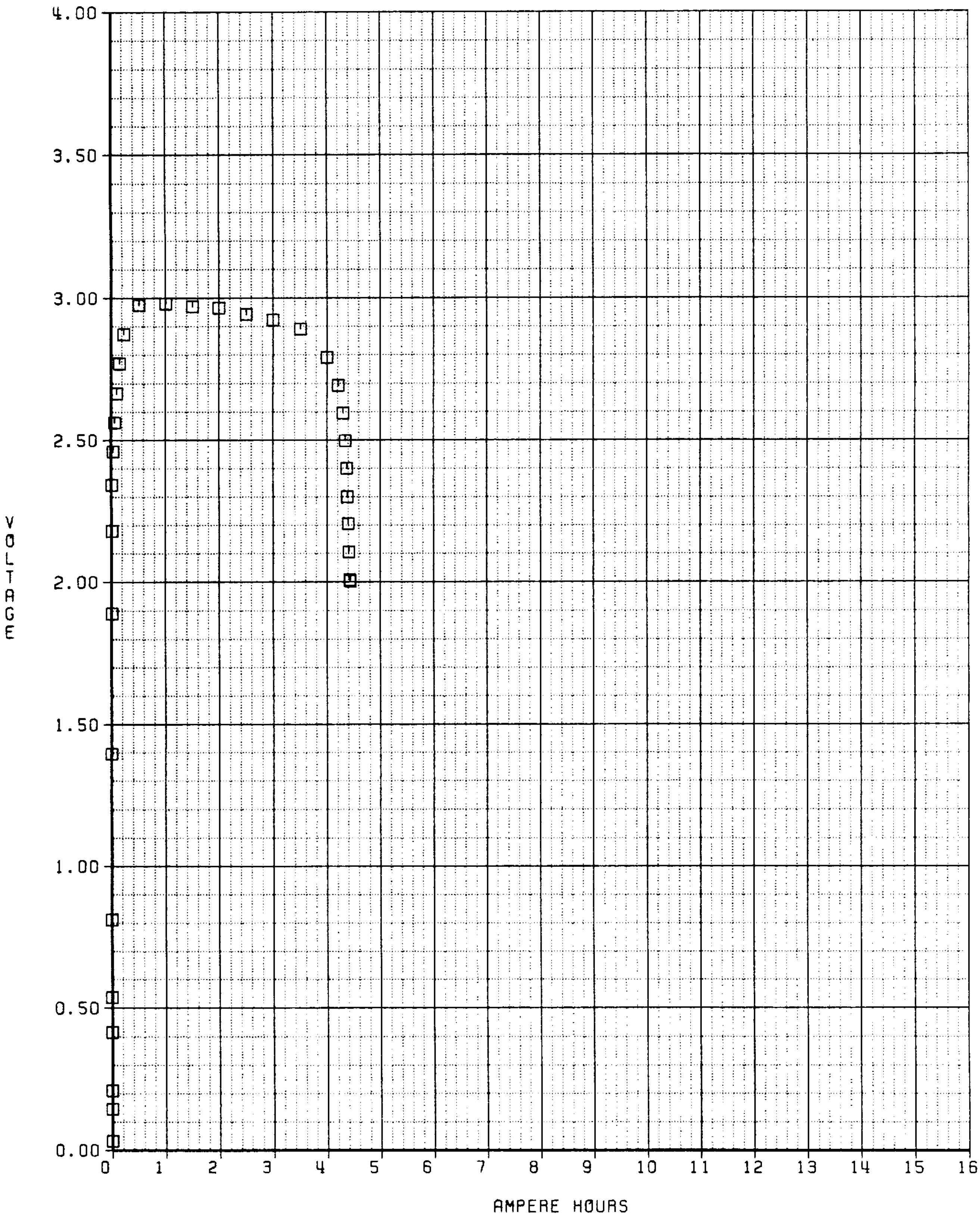

NASA 0.6M LAC BCX D CELL
FRESH/3 AMP DISCHARGE AT RT
MACCOR3 ID 0390 OF NASA D CELL STUDY
WG
VOLTAGE
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
AMPERE HOURS
GPLOT(REV. 3.5)
DAY 063 THU, MAR 04 1993 3:01:44 PM

Figure 64

NASA 1.2M LAC TC D CELL
FRESH/3 AMP DISCHARGE AT RT

MACCOR3 ID 0393R3 OF NASA D CELL STUDY

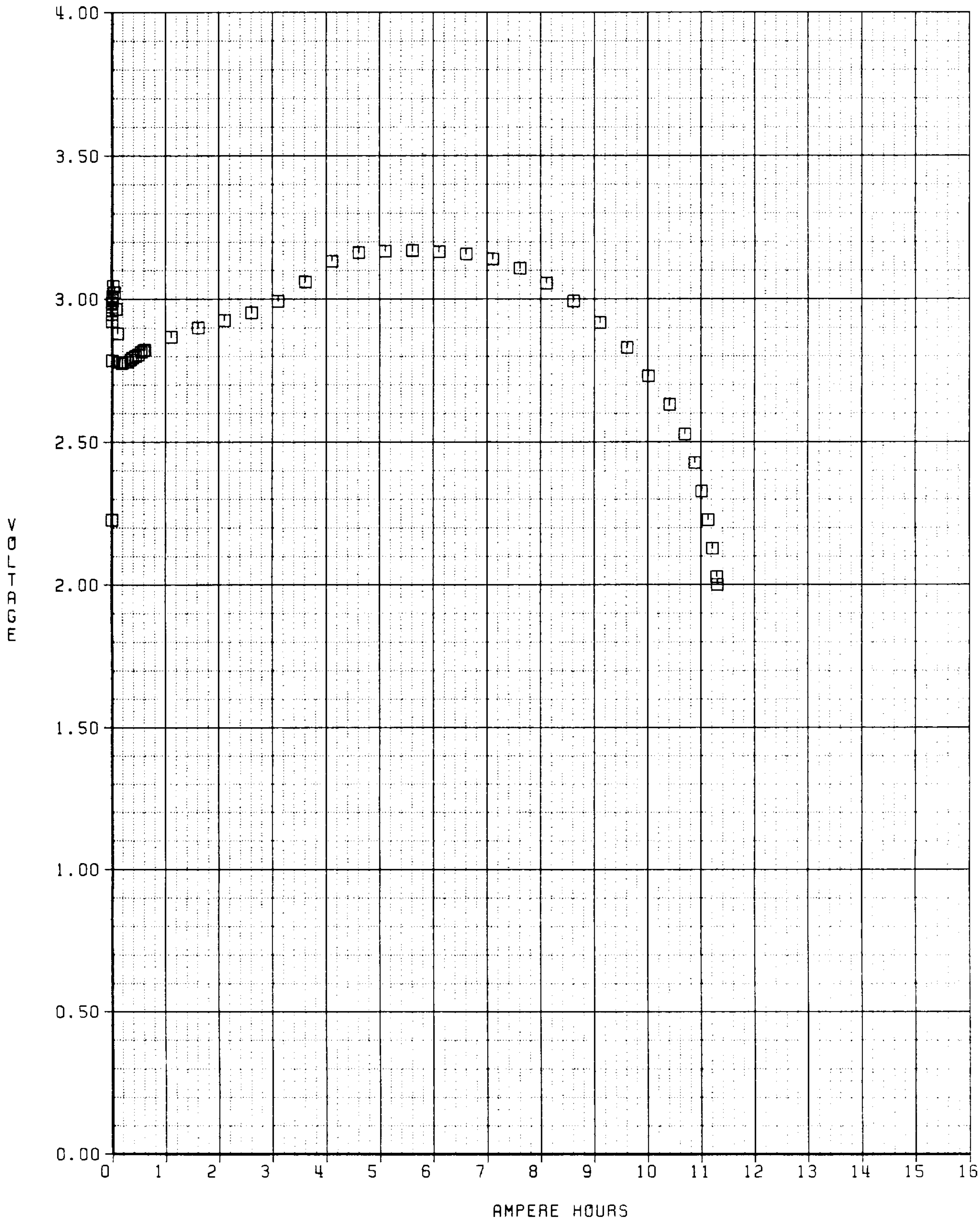


GPLOT(REV. 3.5) DAY 063 THU, MAR 04 1993 3:07:48 PM

Figure 65

NASA 1.8M LAC CSC D CELL
FRESH/3 AMP DISCHARGE AT RT

MACCOR3 ID 0394 OF NASA D CELL STUDY



GPLOT(REV. 3.5)

DAY 062 WED. MAR 03 1993 09:36:07 AM

Figure 66

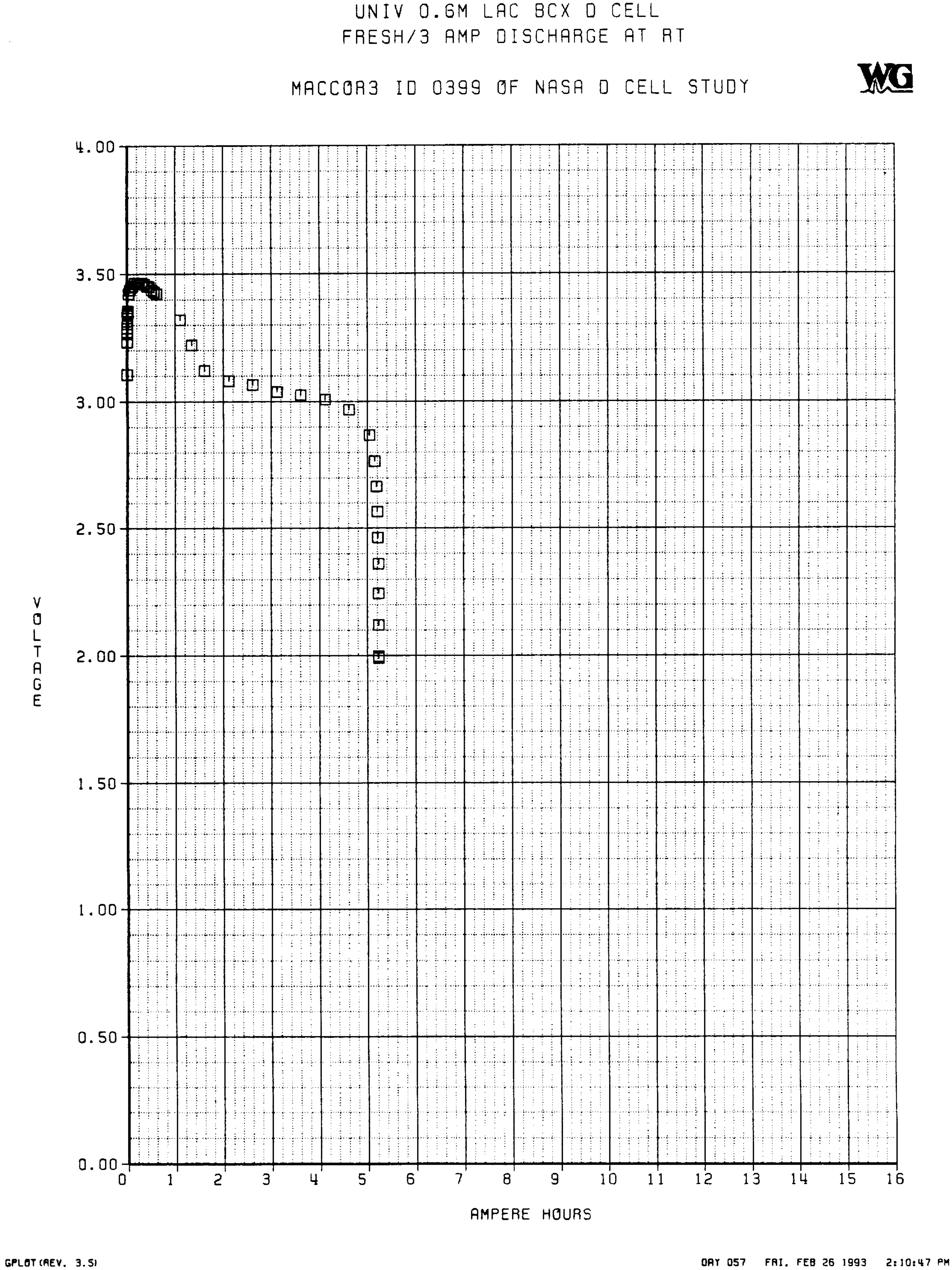
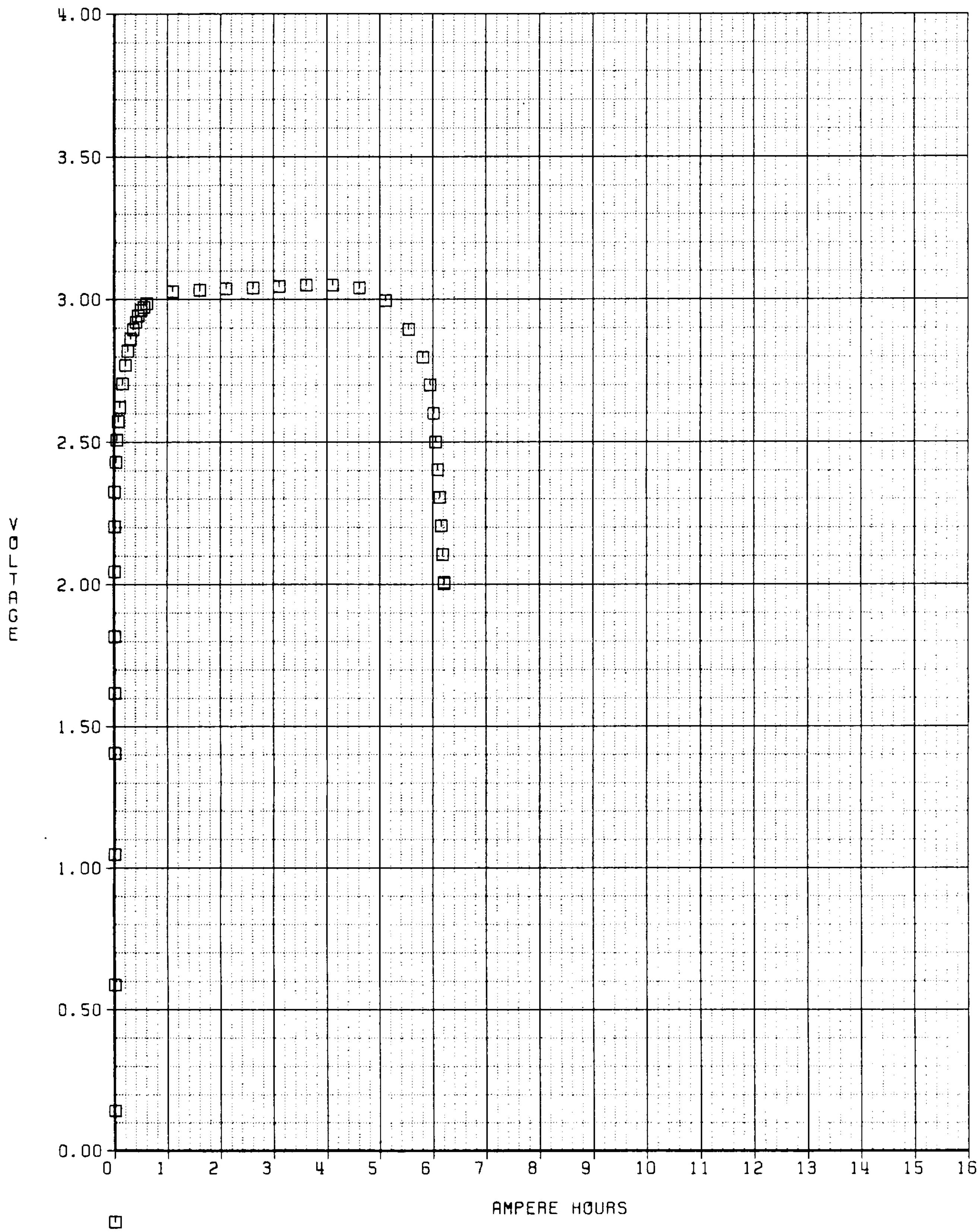

UNIV 0.6M LAC BCX D CELL
FRESH/3 AMP DISCHARGE AT RT
MACCOR3 ID 0399 OF NASA D CELL STUDY
VOLTAGE
AMPERE HOURS
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
GPLOT(REV. 3.5)
DAY 057 FRI. FEB 26 1993 2:10:47 PM

Figure 67

UNIV 1.2M LAC TC D CELL
FRESH/3 AMP DISCHARGE AT RT

MACCOR3 ID 0402 OF NASA D CELL STUDY

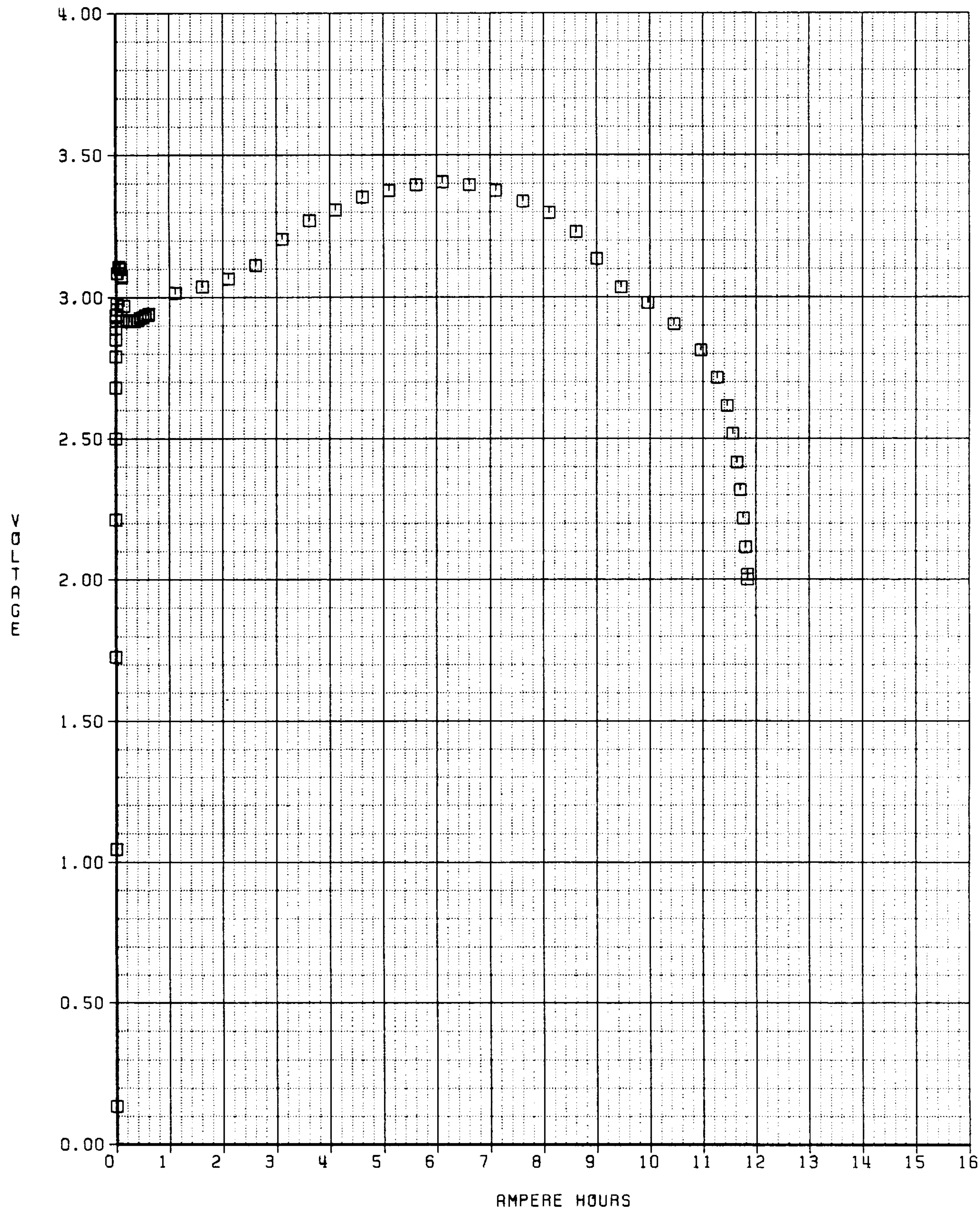


GPLOT(REV. 3.5) DAY 058 SAT. FEB 27 1993 10:31:01 AM

Figure 68

UNIV 1.8M LAC CSC D CELL
FRESH/3 AMP DISCHARGE AT RT

MACCOR3 ID 0403 OF NASA D CELL STUDY



GPLOT(REV. 3.5)

DAY 058 SAT, FEB 27 1993 10:51:07 AM

Figure 69

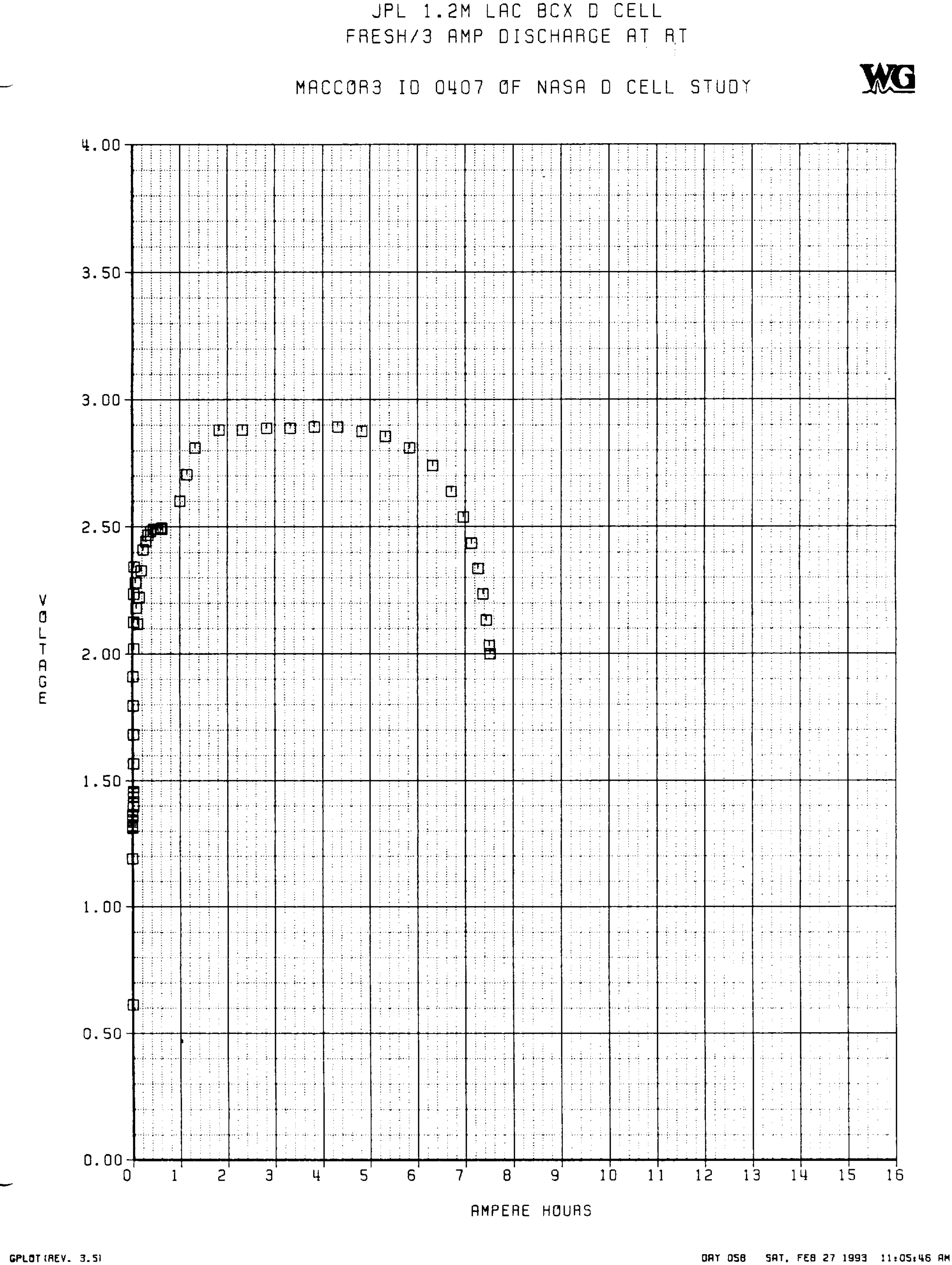

JPL 1.2M LAC BCX D CELL
FRESH/3 AMP DISCHARGE AT RT
MACCOR3 ID 0407 OF NASA D CELL STUDY
WG
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
VOLTAGE
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
AMPERE HOURS
GPLOT(REV. 3.5)
DAY 058 SAT, FEB 27 1993 11:05:46 AM

Figure 70

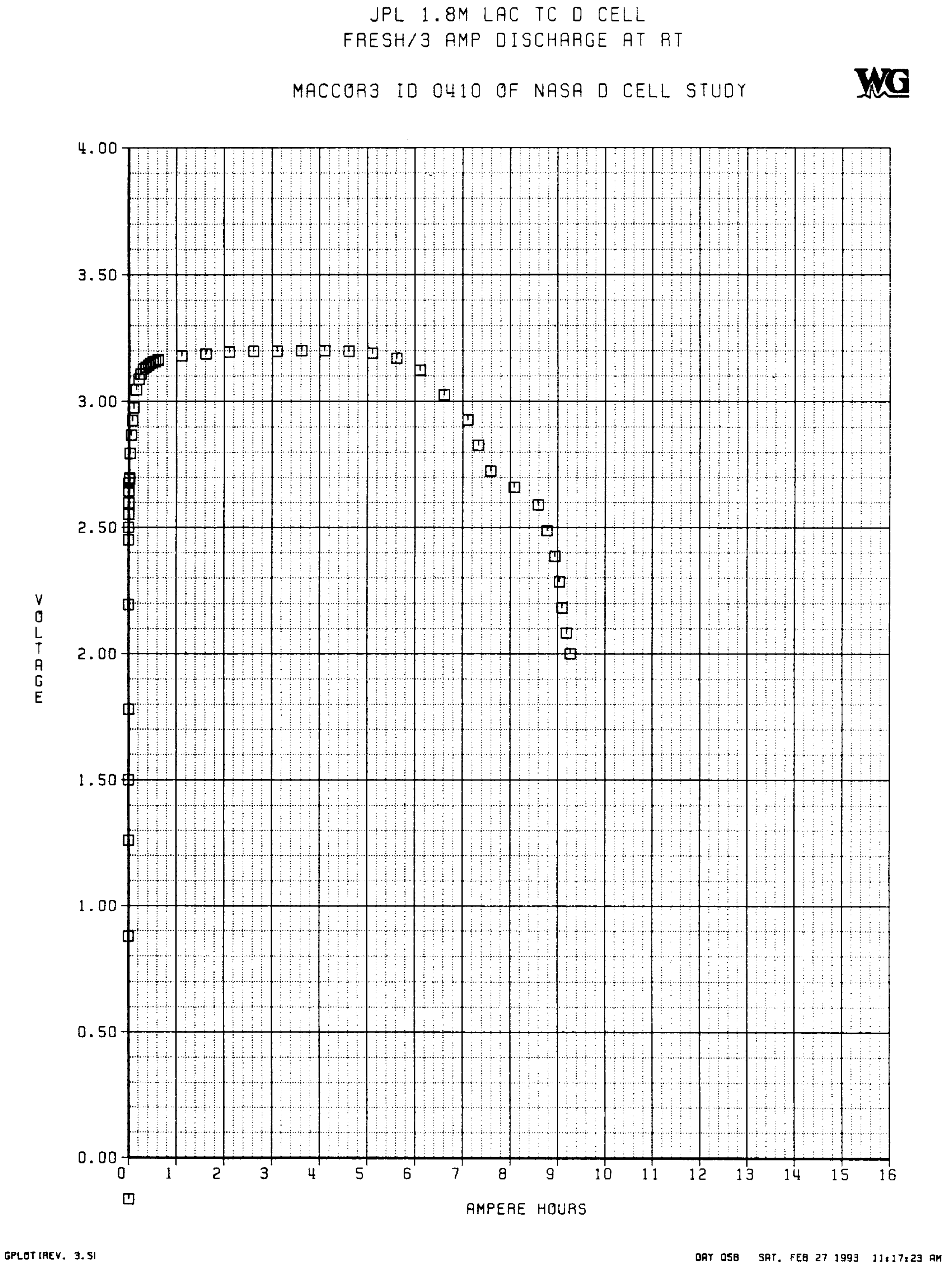

JPL 1.8M LAC TC D CELL
FRESH/3 AMP DISCHARGE AT RT
MACCOR3 ID 0410 OF NASA D CELL STUDY
VOLTAGE
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16
AMPERE HOURS
GPLOT(REV. 3.5)
DAY 058 SAT. FEB 27 1993 11:17:23 AM

Figure 71

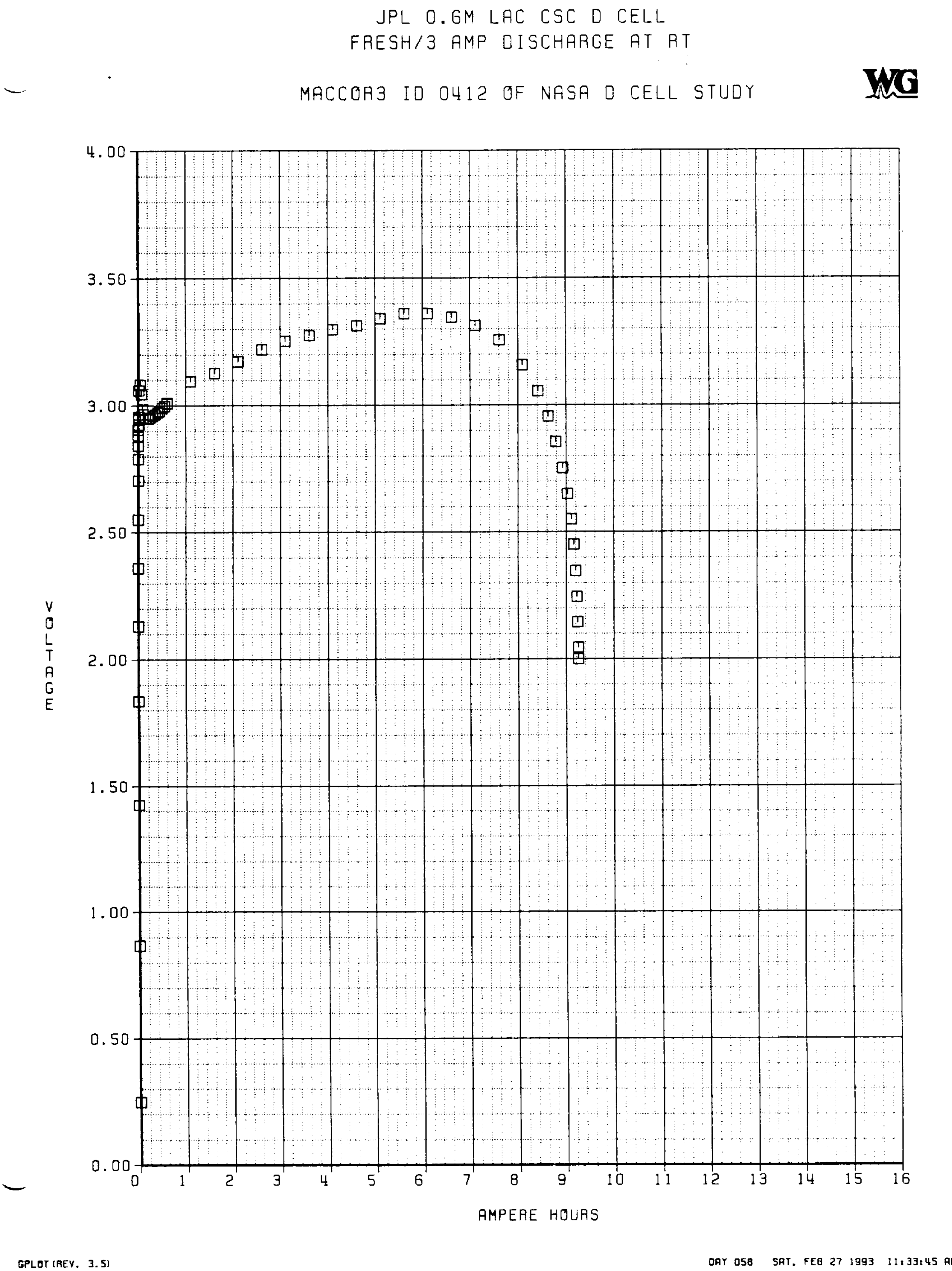
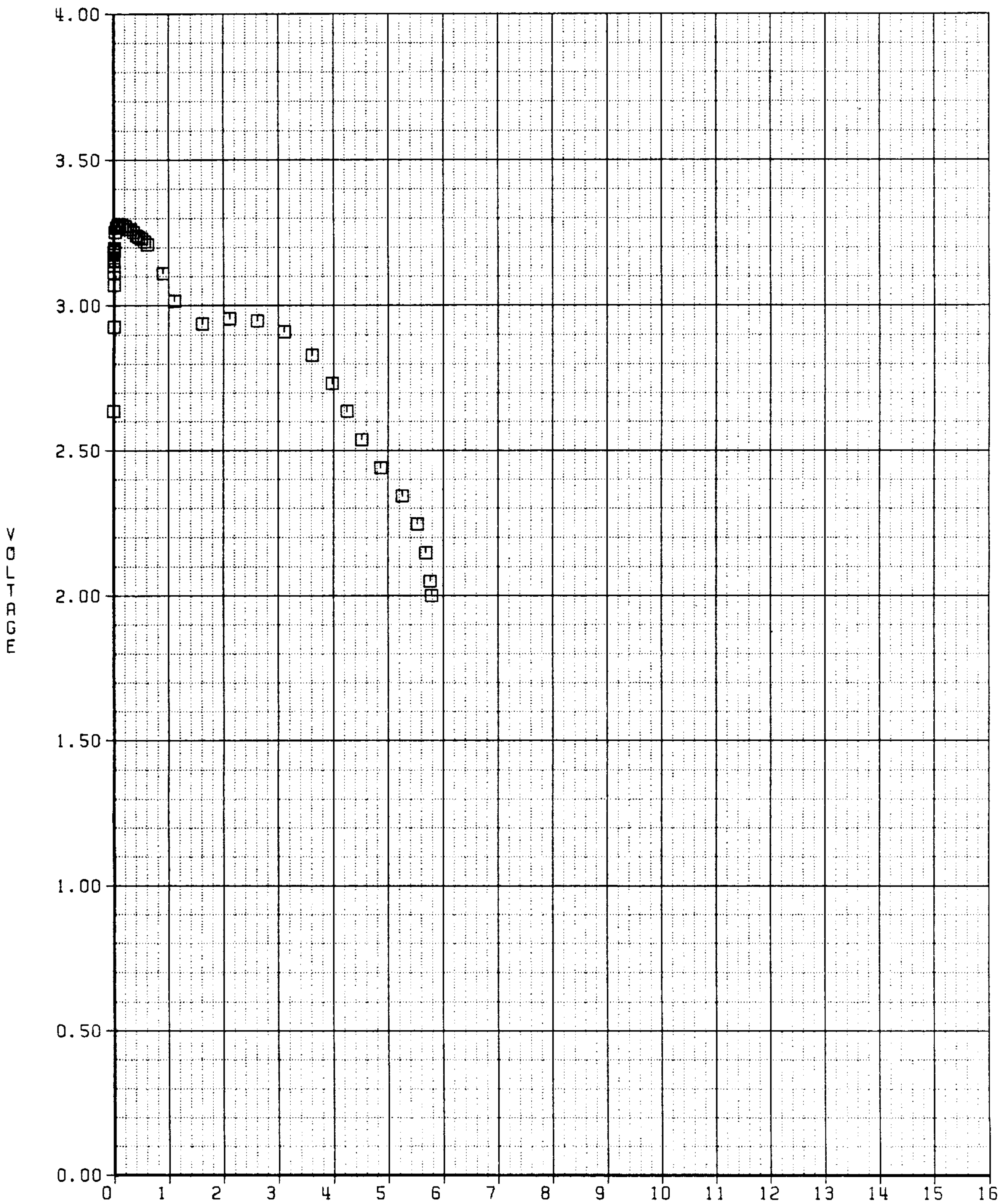

JPL 0.6M LAC CSC D CELL
FRESH/3 AMP DISCHARGE AT RT
MACCOR3 ID 0412 OF NASA D CELL STUDY
WG
VOLTAGE
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
AMPERE HOURS
GPLOT (REV. 3.5)
DAY 058 SAT. FEB 27 1993 11:33:45 AM

Figure 72

NASA 1.8M LGC BCX D CELL
FRESH/3 AMP DISCHARGE AT RT

MACCOR3 ID 0417 OF NASA D CELL STUDY



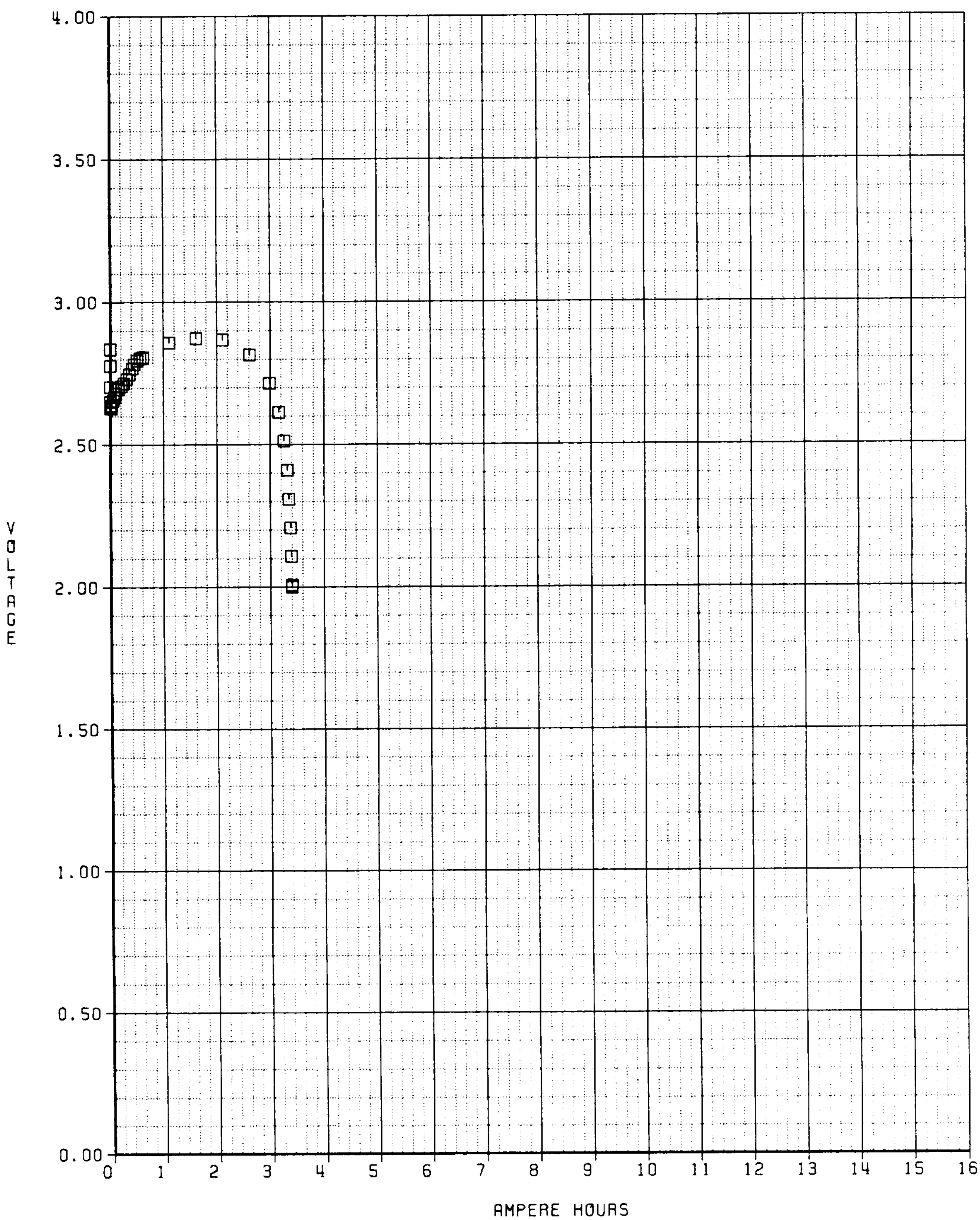
GPLOT (REV. 3.5)

DAY 062 WED. MAR 03 1993 09:10:14 AM

Figure 73

NASA 0.6M LGC TC D CELL
FRESH/3 AMP DISCHARGE AT RT

MACCOR3 ID 0418 OF NASA D CELL STUDY

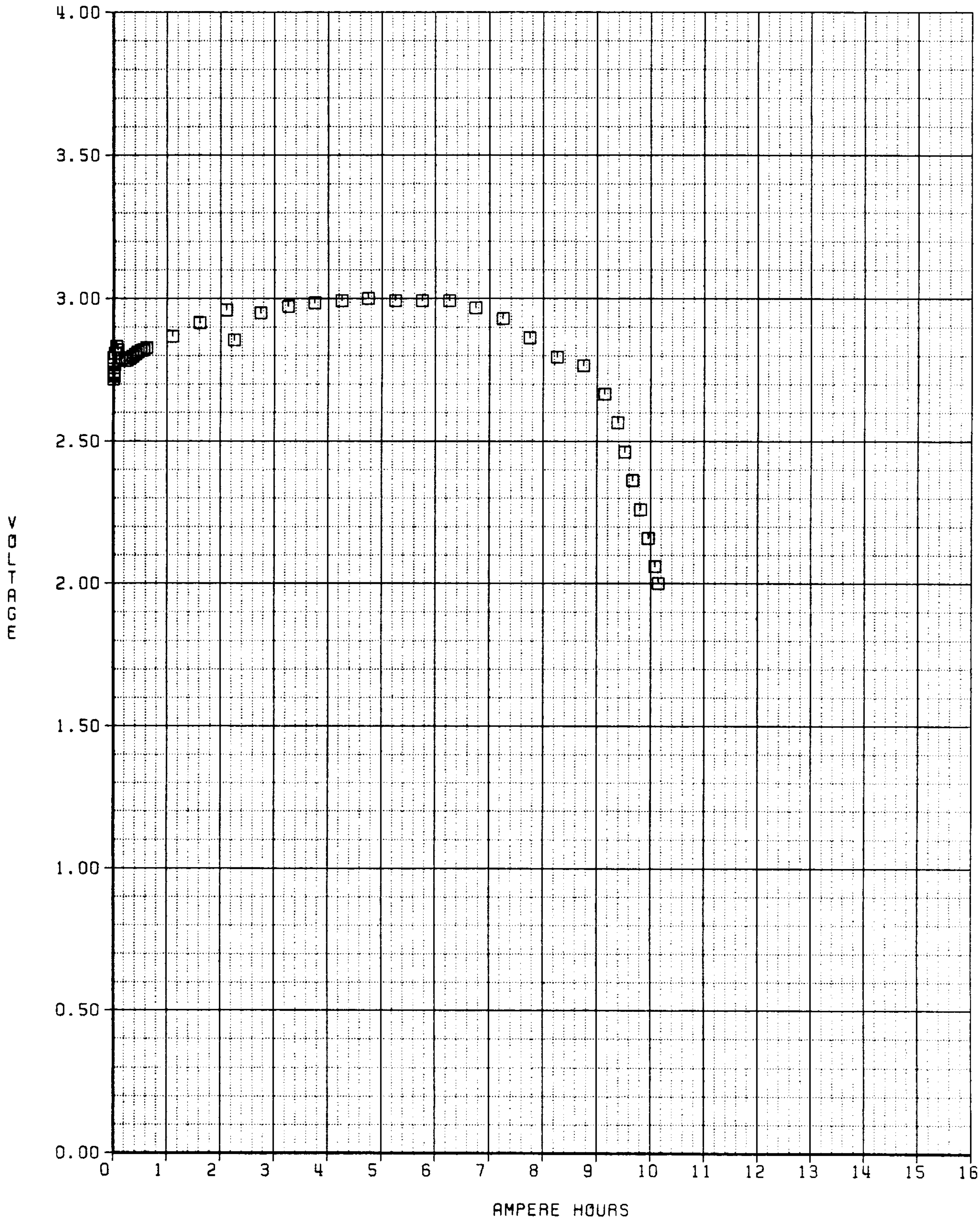


GPLOT(REV. 3.5) DAY 061 TUE, MAR 02 1993 4:02:18 PM

Figure 74

NASA 1.2M LGC CSC D CELL
FRESH/3 AMP DISCHARGE AT RT

MACCOR3 ID 0421 OF NASA D CELL STUDY



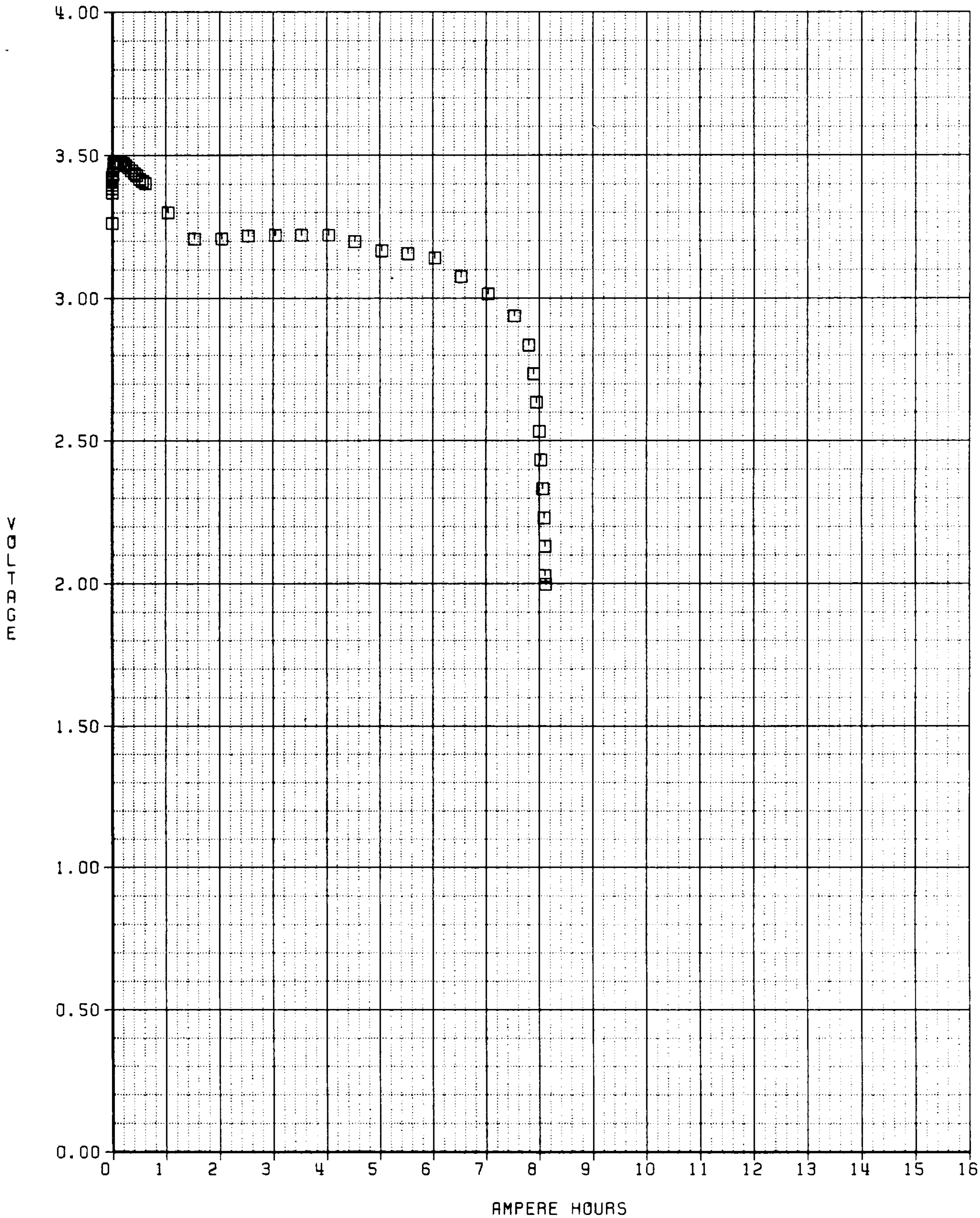
GPLOT(REV. 3.5)

DAY 062 WED. MAR 03 1993 08:33:21 AM

Figure 75

UNIV 1.2M LGC BCX D CELL
FRESH/3 AMP DISCHARGE AT RT

MACCOR3 ID 0425 OF NASA D CELL STUDY

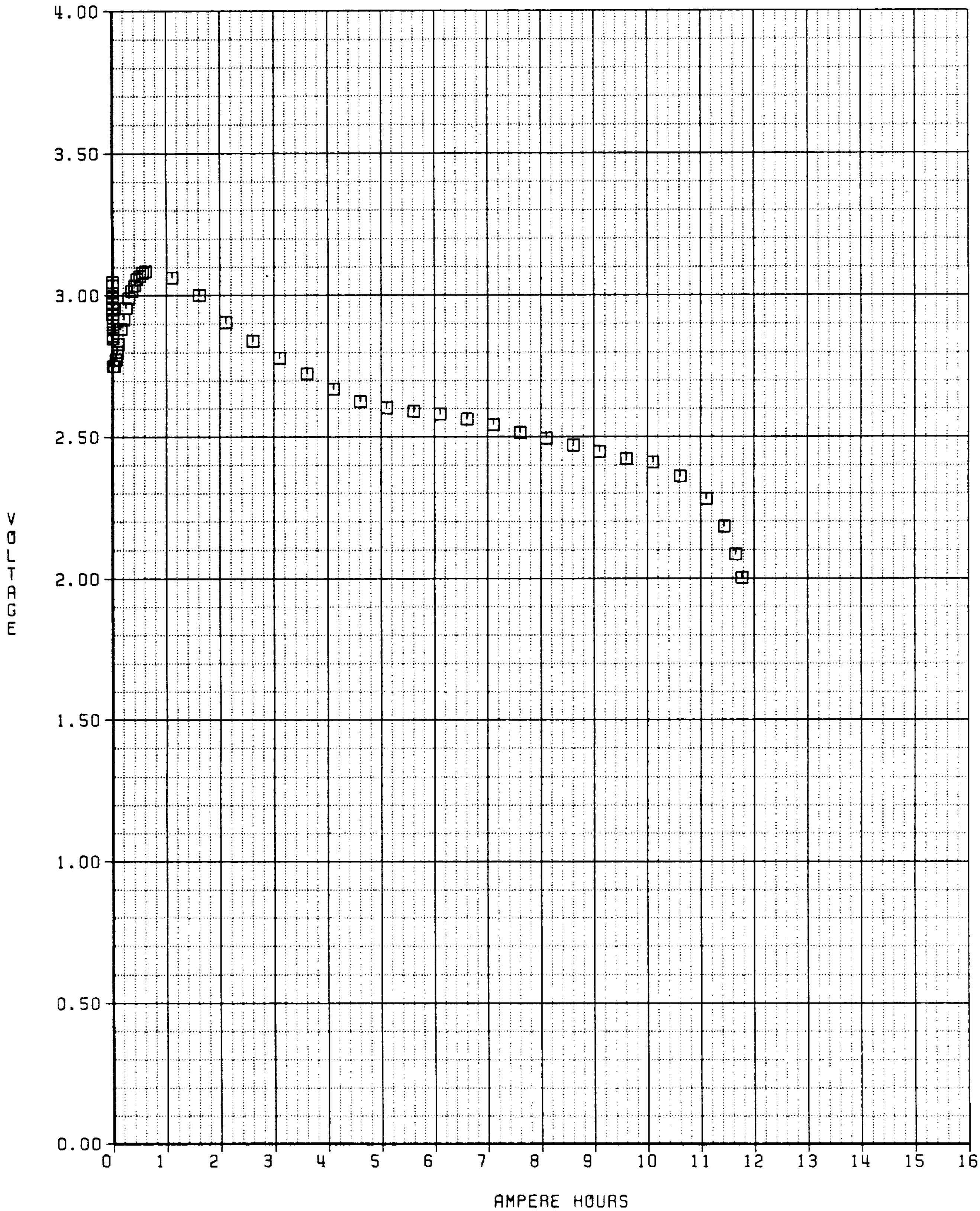


GPLOT(REV. 3.5) DAY 061 TUE, MAR 02 1993 3:40:14 PM

Figure 76

UNIV 1.8M LGC TC D CELL
FRESH/3 AMP DISCHARGE AT RT

MACCOR3 ID 0428 OF NASA D CELL STUDY

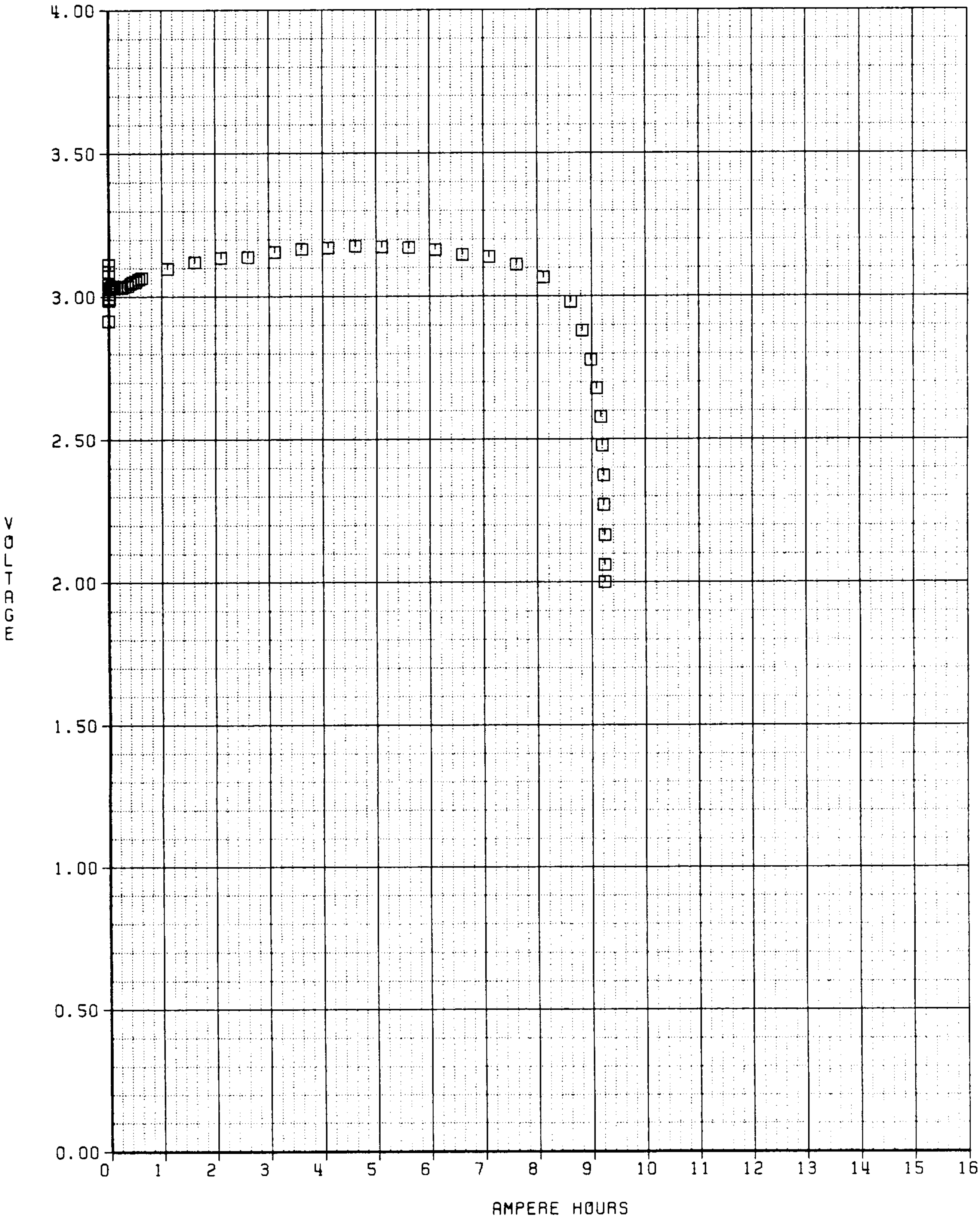


GPLOT(REV. 3.5) DAY 061 TUE. MAR 02 1993 10:01:27 AM

Figure 77

UNIV 0.6M LGC CSC D CELL
FRESH/3 AMP DISCHARGE AT RT

MACCOR3 ID 0432 OF NASA D CELL STUDY



GPLOT(REV. 3.5)

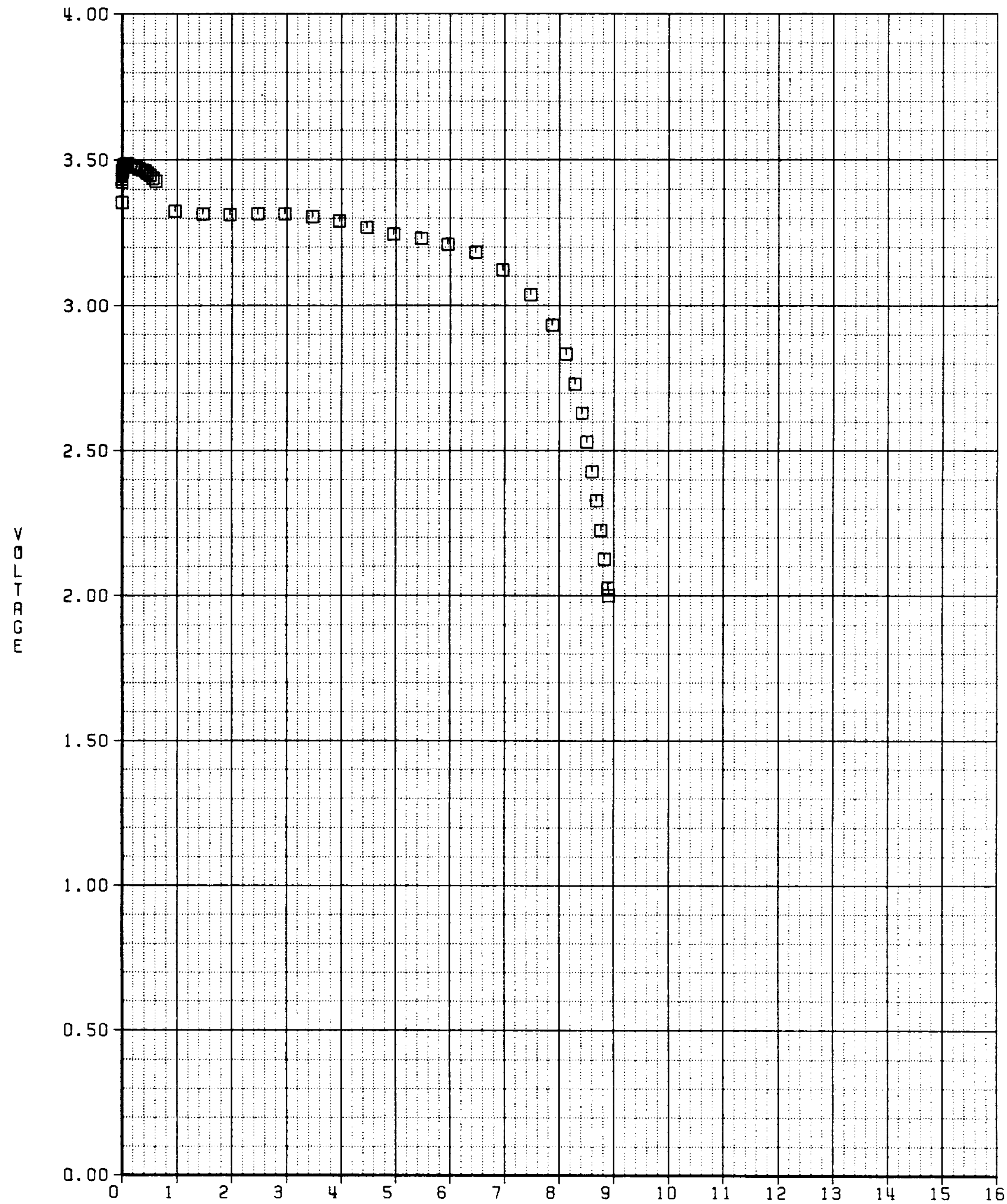
DAY 060 MON, MAR 01 1993 3:56:43 PM

Figure 78

JPL 1.8M LGC BCX D CELL

FRESH/3 AMP DISCHARGE AT RT

MACCOR3 ID 0433 OF NASA D CELL STUDY



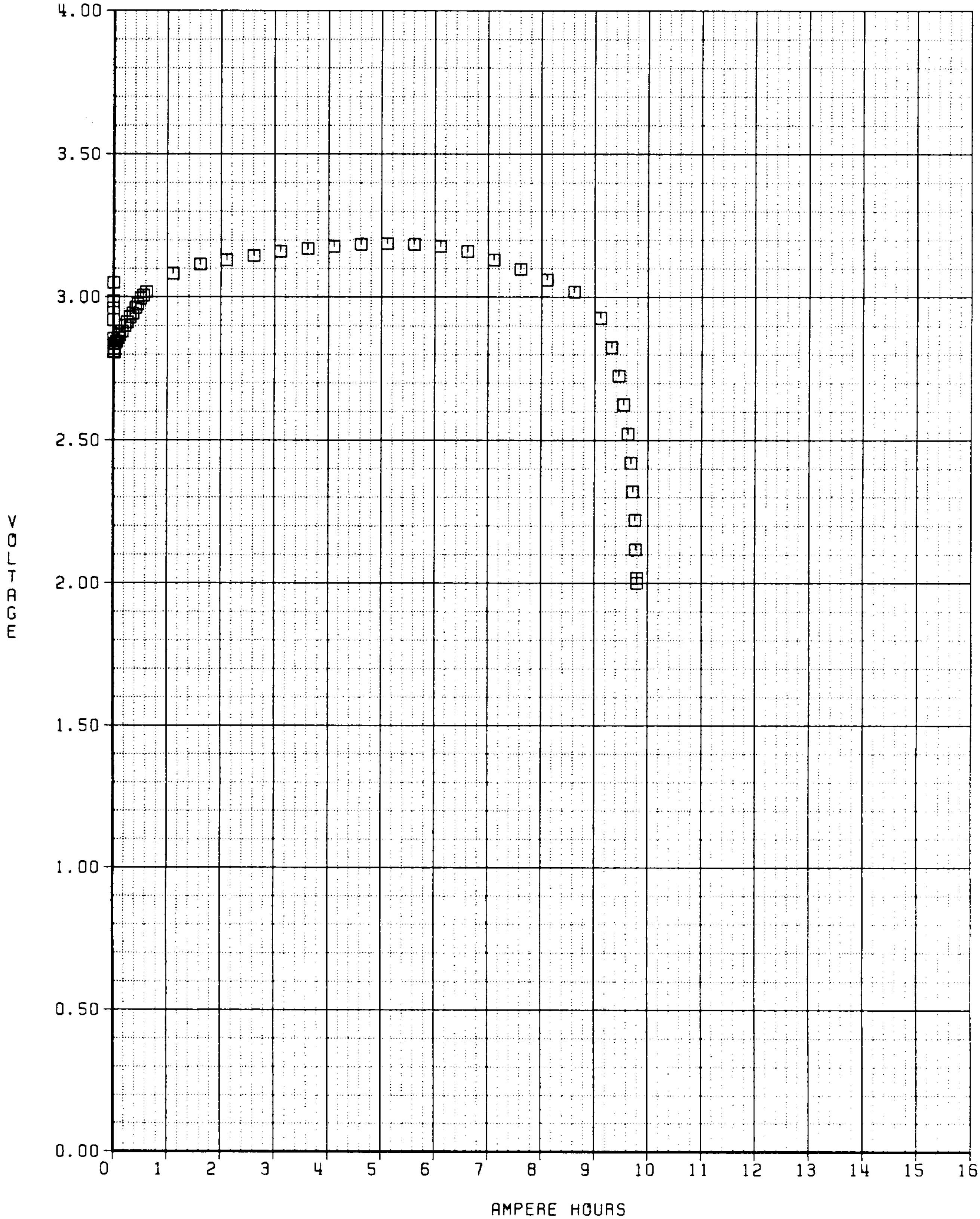
GPLOT(REV. 3.5)

DAY 058 SAT. FEB 27 1993 11:43:59 AM

Figure 79

JPL 0.6M LGC TC D CELL
FRESH/3 AMP DISCHARGE AT RT

MACCOR3 ID 0436 OF NASA D CELL STUDY



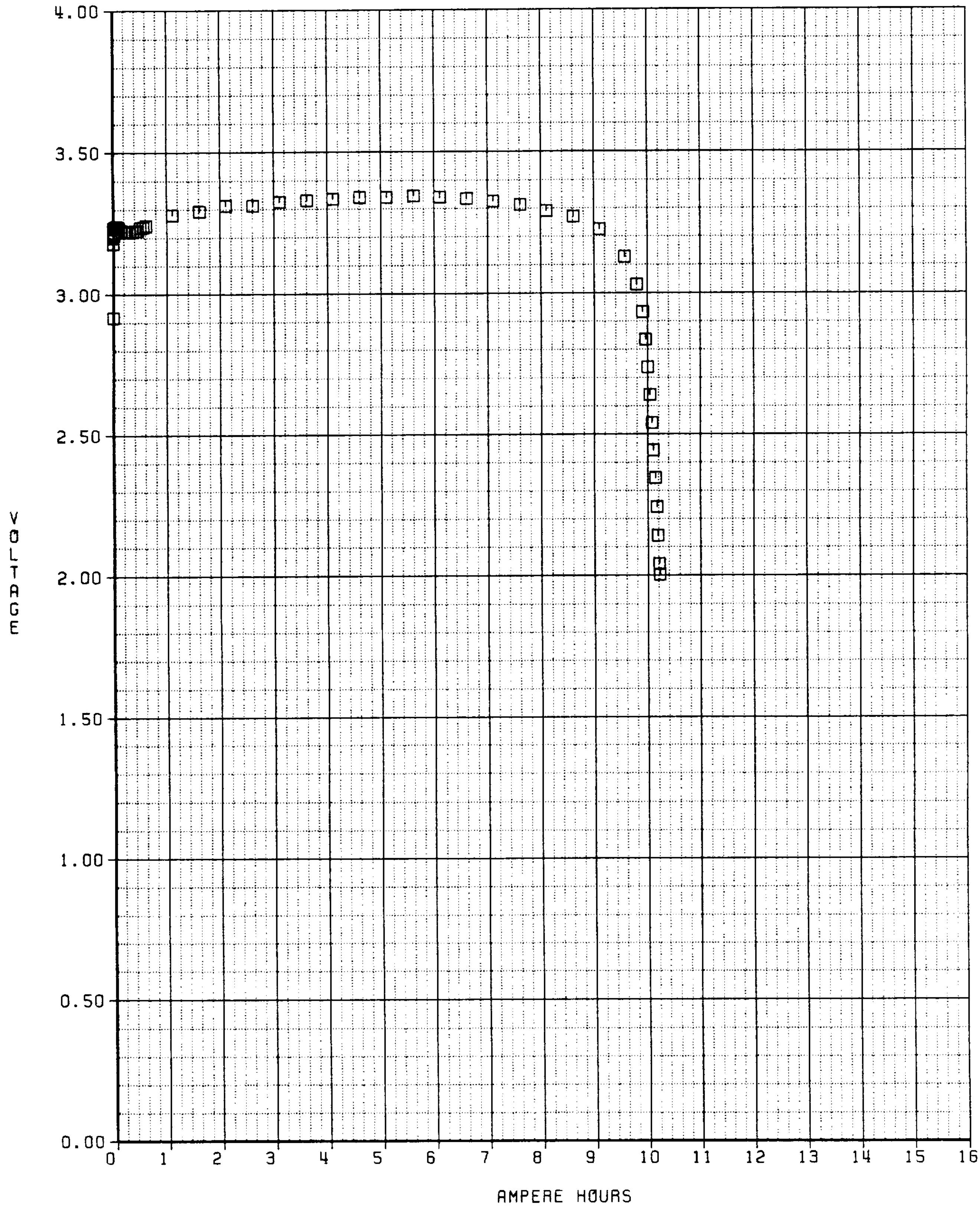
GPLOT(REV. 3.5)

DAY 058 SAT. FEB 27 1993 11:54:14 AM

Figure 80

JPL 1.2M LGC CSC D CELL
FRESH/3 AMP DISCHARGE AT RT

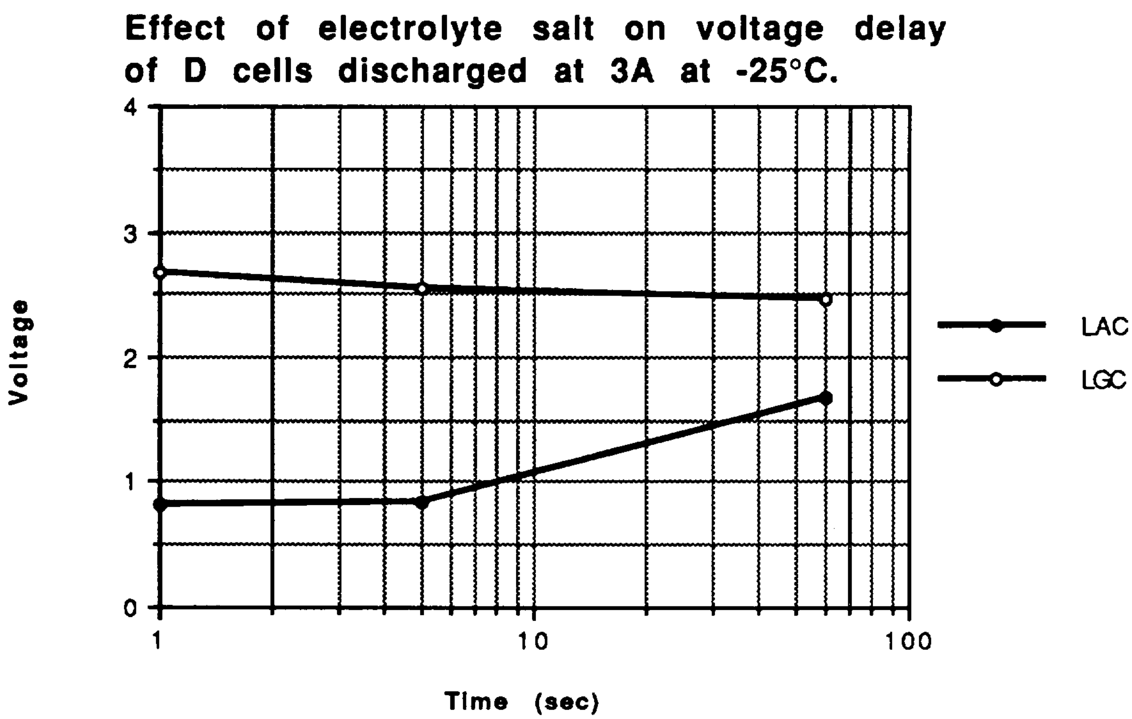
MACCOR3 ID 0440 OF NASA D CELL STUDY



GPLOT(REV. 3.5)

DAY 058 SAT. FEB 27 1993 12:03:30 PM

Figure 81



Effect of electrolyte salt on voltage delay of D cells discharged at 3A at -25°C.
Voltage
4
3
2
1
0
1
10
100
Time (sec)
LAC
LGC

C-2

Figure 82

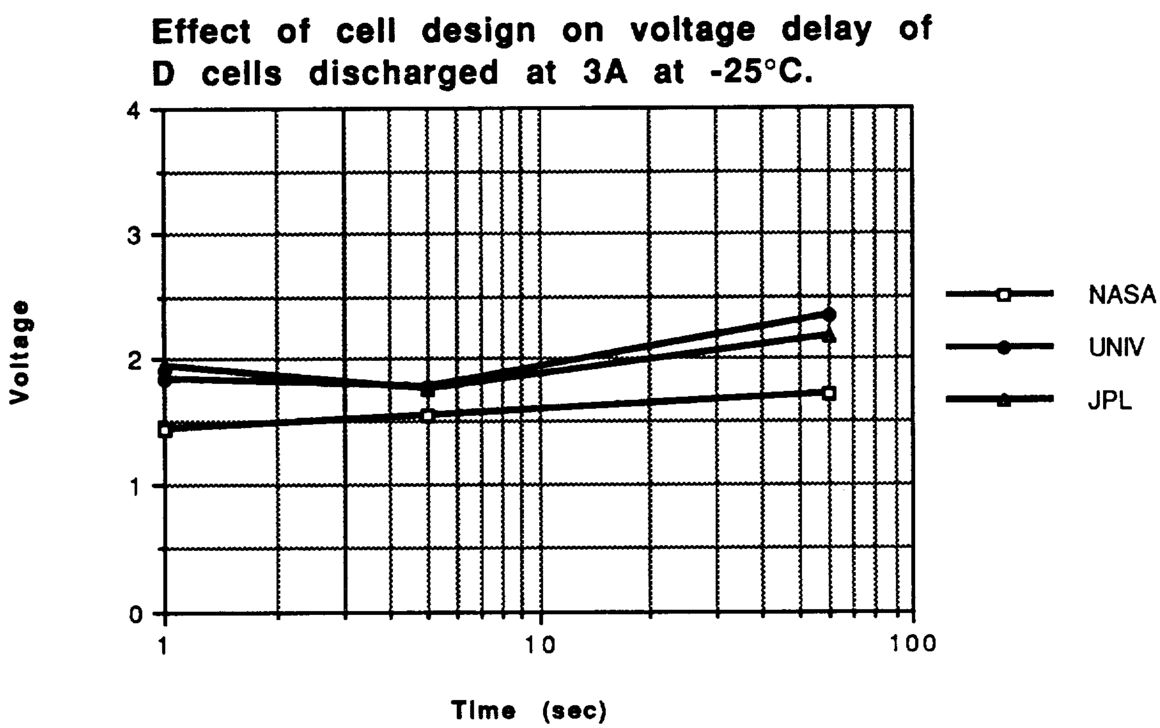

Effect of cell design on voltage delay of
D cells discharged at 3A at -25°C.
Voltage
4
3
2
1
0
1
10
100
Time (sec)
NASA
UNIV
JPL

Figure 83

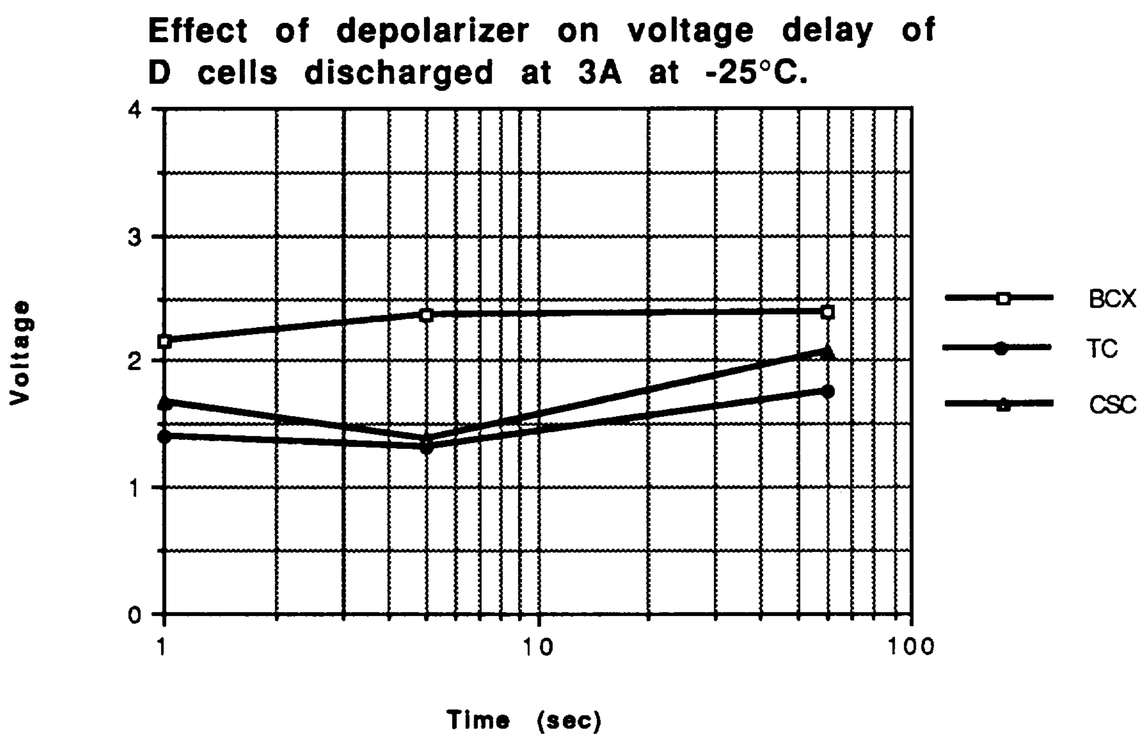
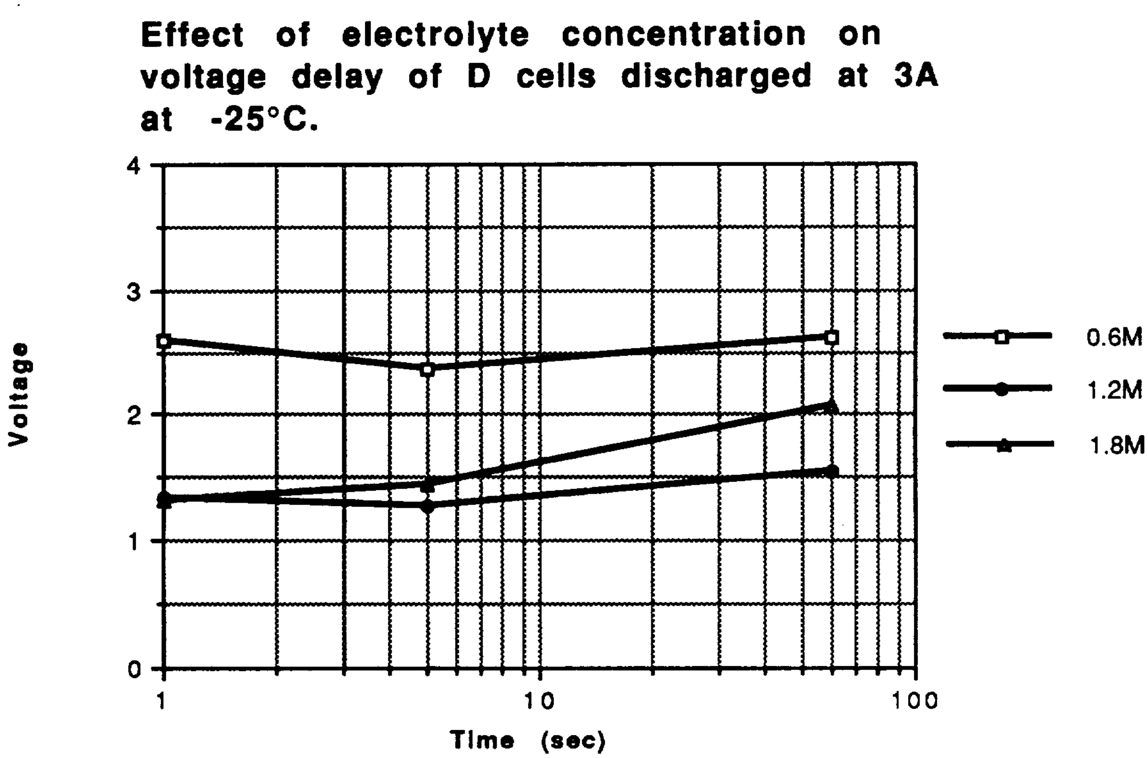

Effect of depolarizer on voltage delay of D cells discharged at 3A at -25°C.
Voltage
Time (sec)
0
1
2
3
4
1
10
100
BCX
TC
CSC

Figure 84



Effect of electrolyte concentration on voltage delay of D cells discharged at 3A at -25°C.
Voltage
4
3
2
1
0
1
10
100
Time (sec)
0.6M
1.2M
1.8M

Figure 85

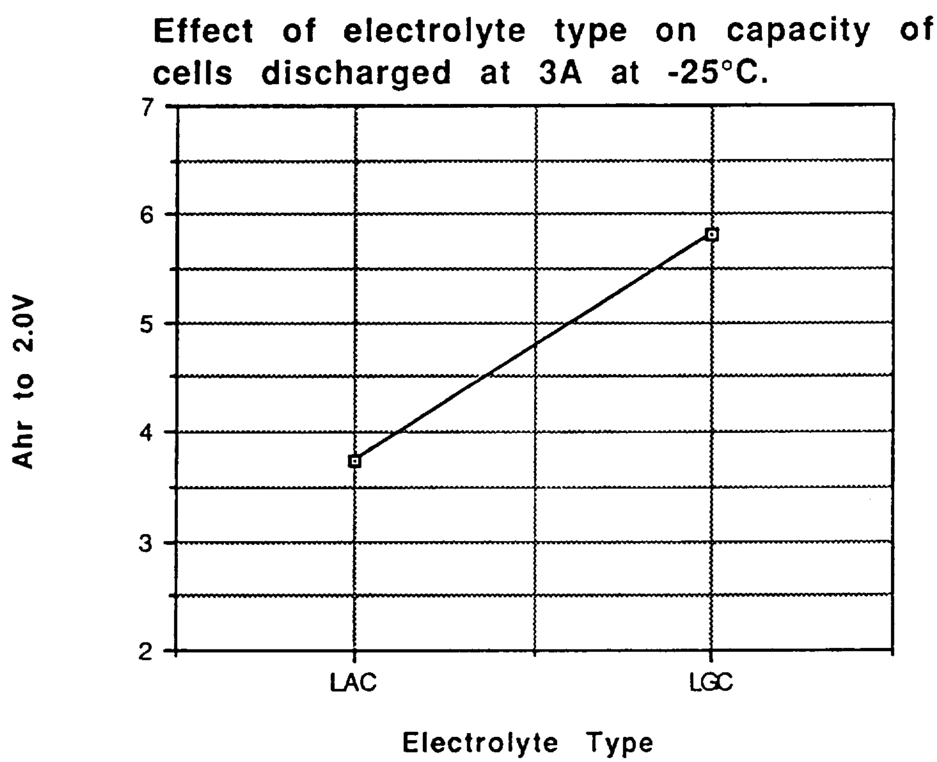

Effect of electrolyte type on capacity of cells discharged at 3A at -25°C.
7
6
5
4
3
2
Ahr to 2.0V
LAC
LGC
Electrolyte Type

Figure 86

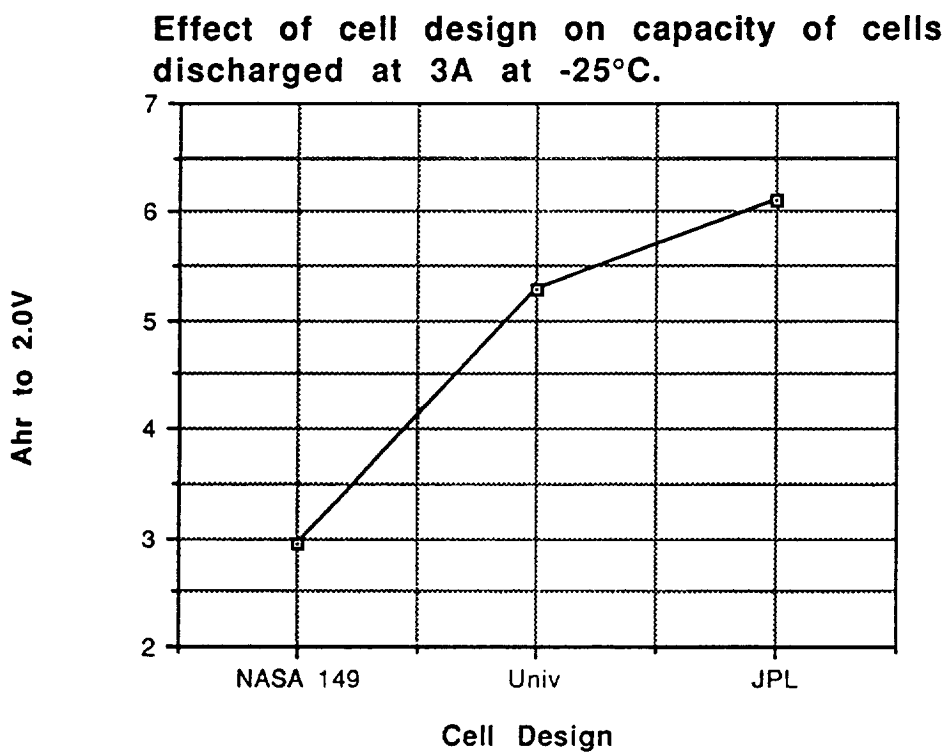

Effect of cell design on capacity of cells discharged at 3A at -25°C.
Ahr to 2.0V
7
6
5
4
3
2
NASA 149
Univ
JPL
Cell Design

Figure 87

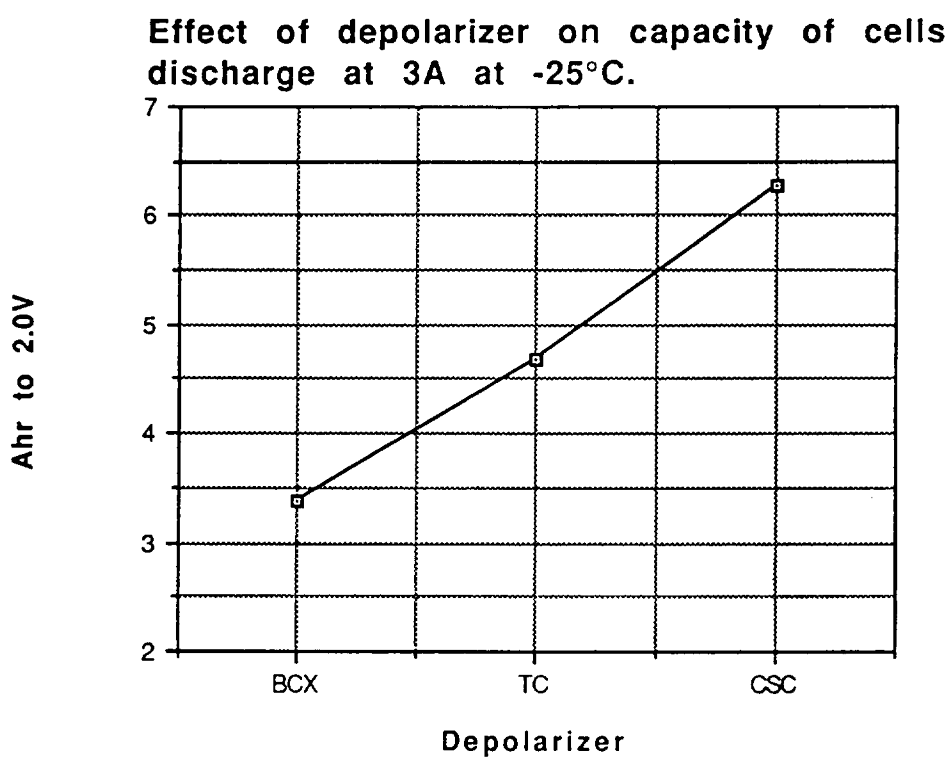
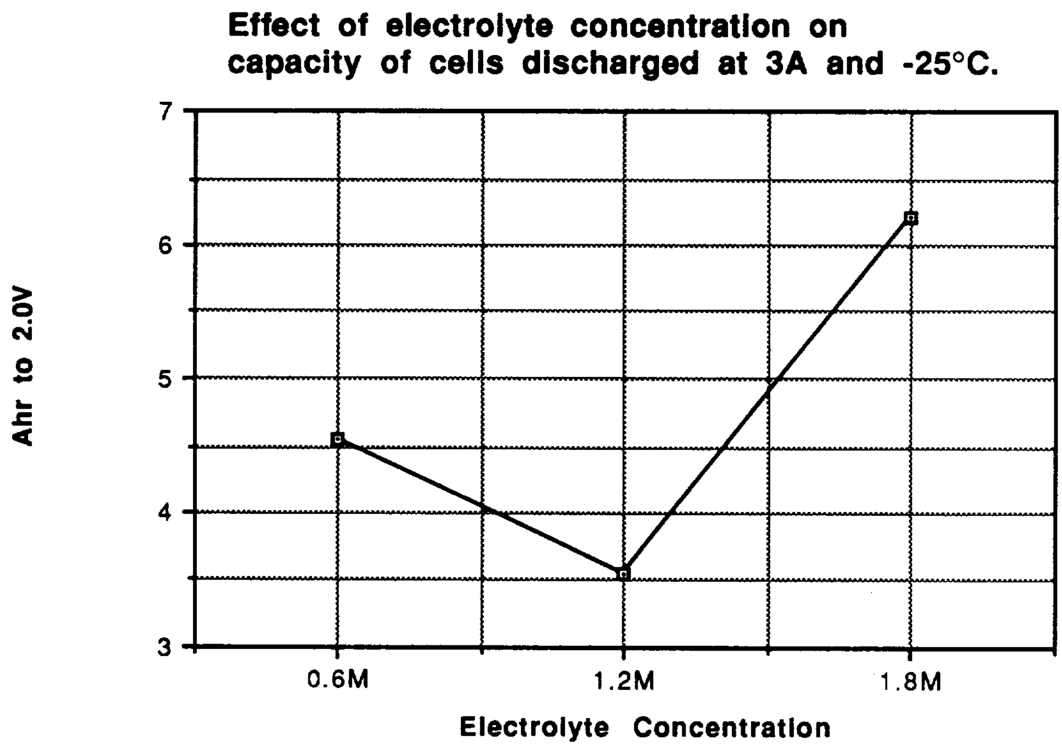

Effect of depolarizer on capacity of cells discharge at 3A at -25°C.
Ahr to 2.0V
7
6
5
4
3
2
BCX
TC
CSC
Depolarizer

Figure 88


Effect of electrolyte concentration on
capacity of cells discharged at 3A and -25°C.
Ahr to 2.0V
7
6
5
4
3
0.6M
1.2M
1.8M
Electrolyte Concentration

attached in figures 89 - 105. One group did not discharge above 1.8V and is therefore not represented by a discharge curve.

5.5 1A ROOM TEMPERATURE PERFORMANCE AFTER 1 YEAR

Fifty four D cells were discharged at a constant current of 1A at room temperature after a 1 year storage period at room temperature. Under these conditions, several cells failed to operate and 14 of 18 that did not function were cells containing the LAC electrolyte. Figure 106 represents the effect of the electrolyte salt on start up capabilities of D cells under these conditions. The electrolyte salt accounts for 18.7% of the variation in the voltage at 1 second, and the LGC salt is superior to the LAC salt. At the end of the 60 second test, the cells with LGC electrolyte recovered to 2.77V and cells with LAC electrolyte recovered to 1.47V. At this point the electrolyte type accounts for 17.4% of the variation in voltage. The depolarizer plays a similar role in voltage delay and figure 108 shows that BCX once again performs better than either thionyl chloride or CSC depolarizer. The cell design does not affect voltage delay to any extent and the electrolyte concentration effects voltage delay only slightly. As in the fresh discharge data obtained, the lower molarity electrolyte aids in voltage recovery. (See figures 107 & 109).

The running voltage at 50% DOD is affected by the electrolyte type and the depolarizer with 61.8% of the variation due to outside noise. The electrolyte type accounts for 17.4% and the depolarizer accounts for 14% of the variation in running voltage. Cells with LGC electrolyte typically ran 1.3V higher than cells with LAC electrolyte and cells with BCX depolarizer ran 1.0 - 1.5V higher than TC and CSC, respectively. Figures 110 - 113 illustrate the effects of the four factors on running voltage.

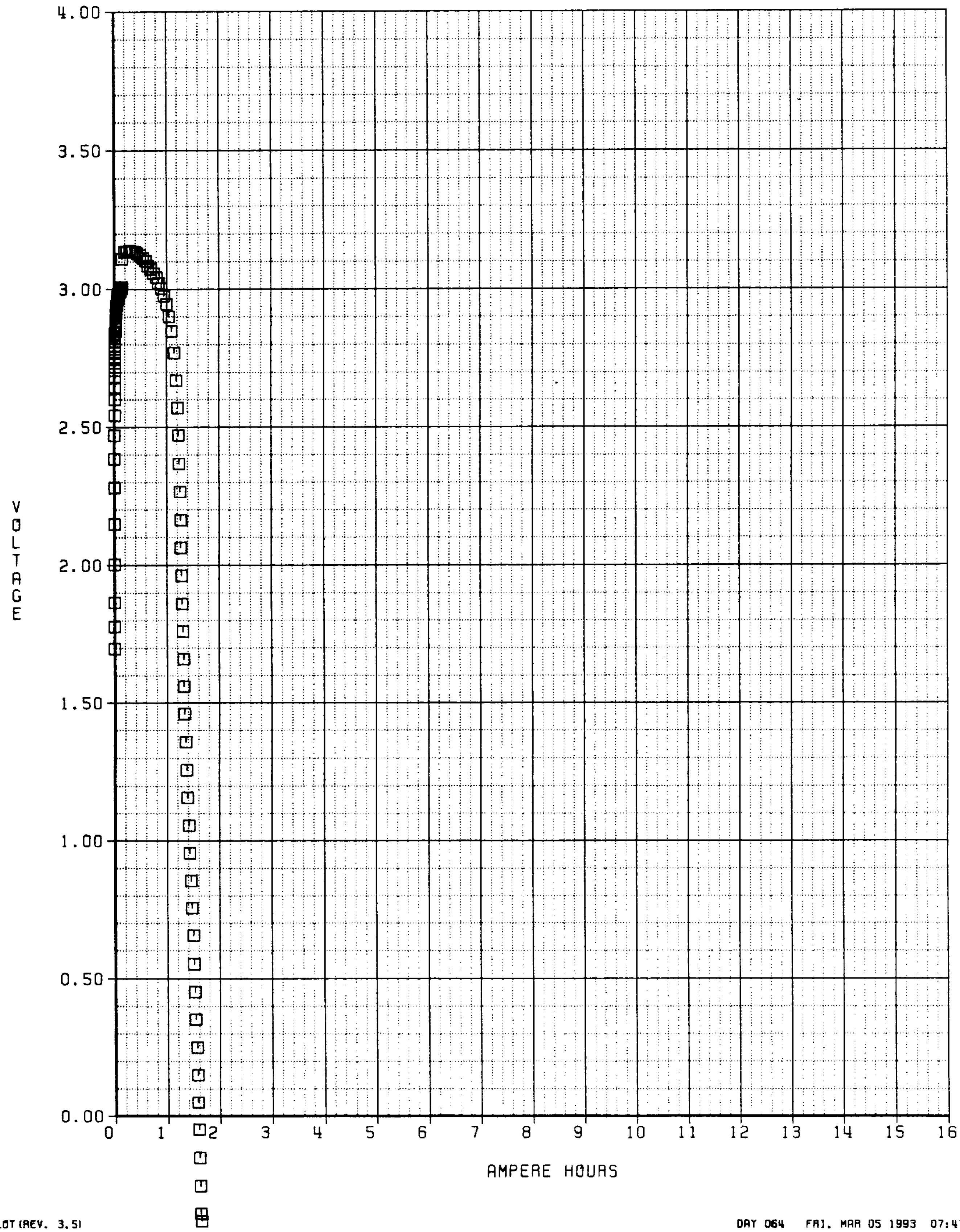
The capacity of D discharged under these conditions was affected the most by the electrolyte type, where the electrolyte accounted for 44.3% of the variation in capacity. 52% of the cells containing LAC electrolyte could not carry the 1A load after the long term storage period compared to 15% of the cells containing LGC electrolyte. The average capacity of cells containing LGC electrolyte was 8.6 Ah and the average for cells with LAC electrolyte was 2.4 Ah. Figure 114 illustrates the main effects of the electrolyte type. The remaining three factors had little to no affect on capacity, accounting for a total of 9.6% of the variation. (See figures 115 - 117).

The effect of the four factors on capacity retention was calculated based on the difference in delivered capacity between the fresh cells and those stored for 1 year. Results are

Figure 89

NASA 0.6M LAC BCX D CELL
FRESH/3 AMP DISCHARGE AT -25^{0}C

MACCOR3 ID 0444 OF NASA D CELL STUDY



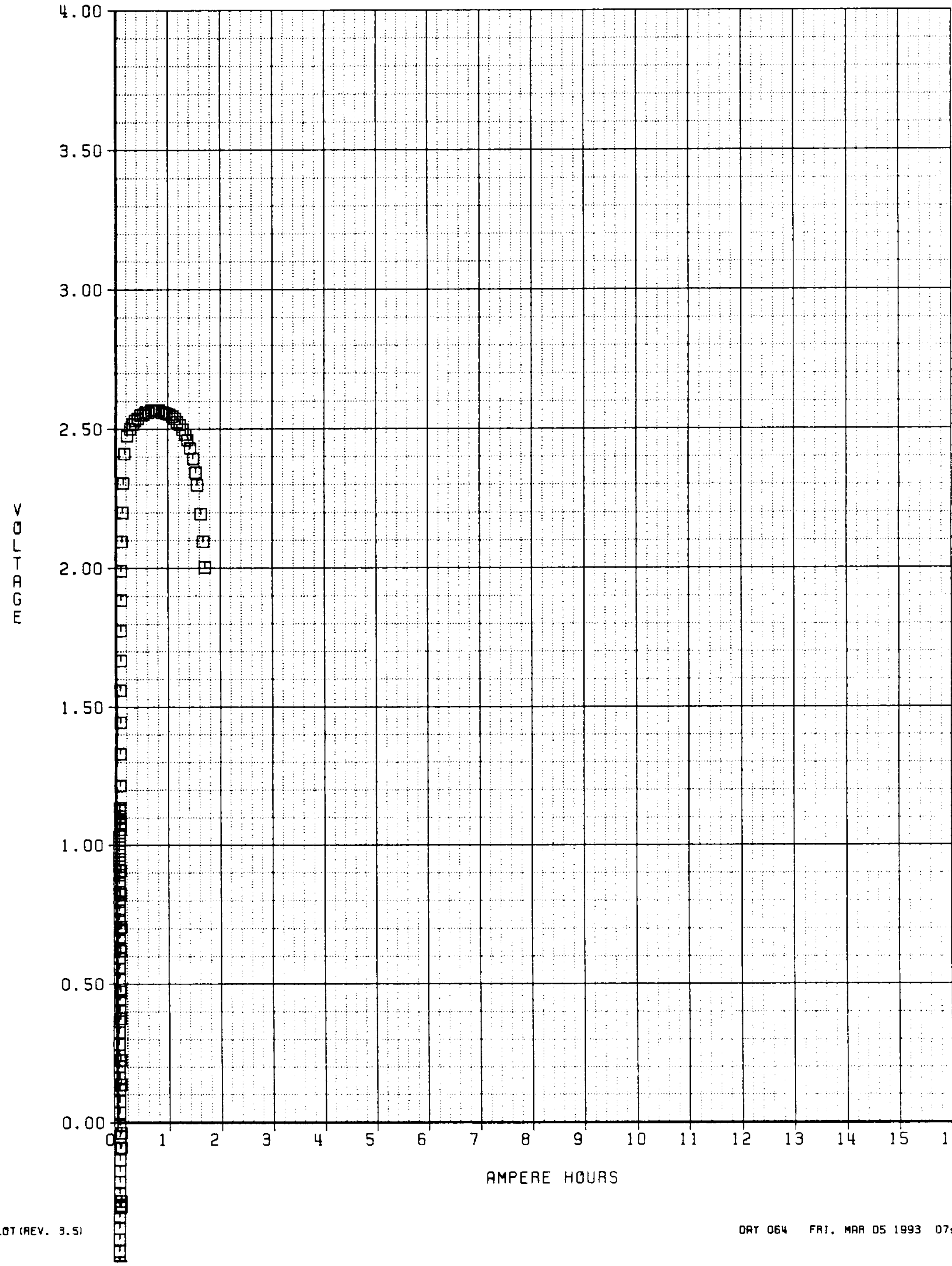
GPLOT(REV. 3.5)

DAY 064 FRI. MAR 05 1993 07:47:38 AM

Figure 90

NASA 1.2M LAC TC D CELL
FRESH/3 AMP DISCHARGE AT -25°C

MACCOR3 ID 0447 OF NASA D CELL STUDY

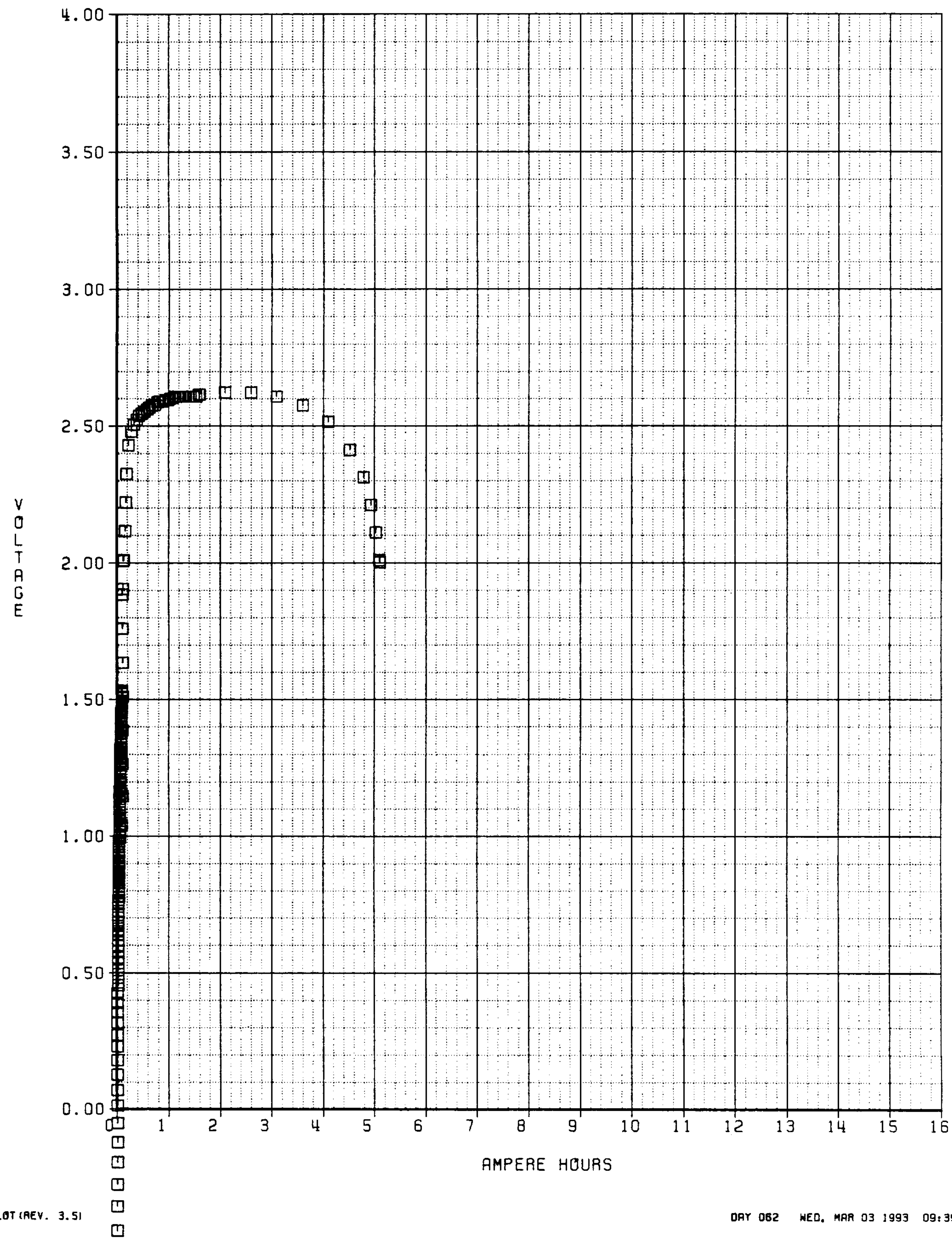


GPLOT(REV. 3.5) DAT 064 FRI. MAR 05 1993 07:43:40 AM

Figure 91

NASA 1.8M LAC CSC D CELL
FRESH/3 AMP DISCHARGE AT -25°C

MACCOR3 ID 0449 OF NASA D CELL STUDY



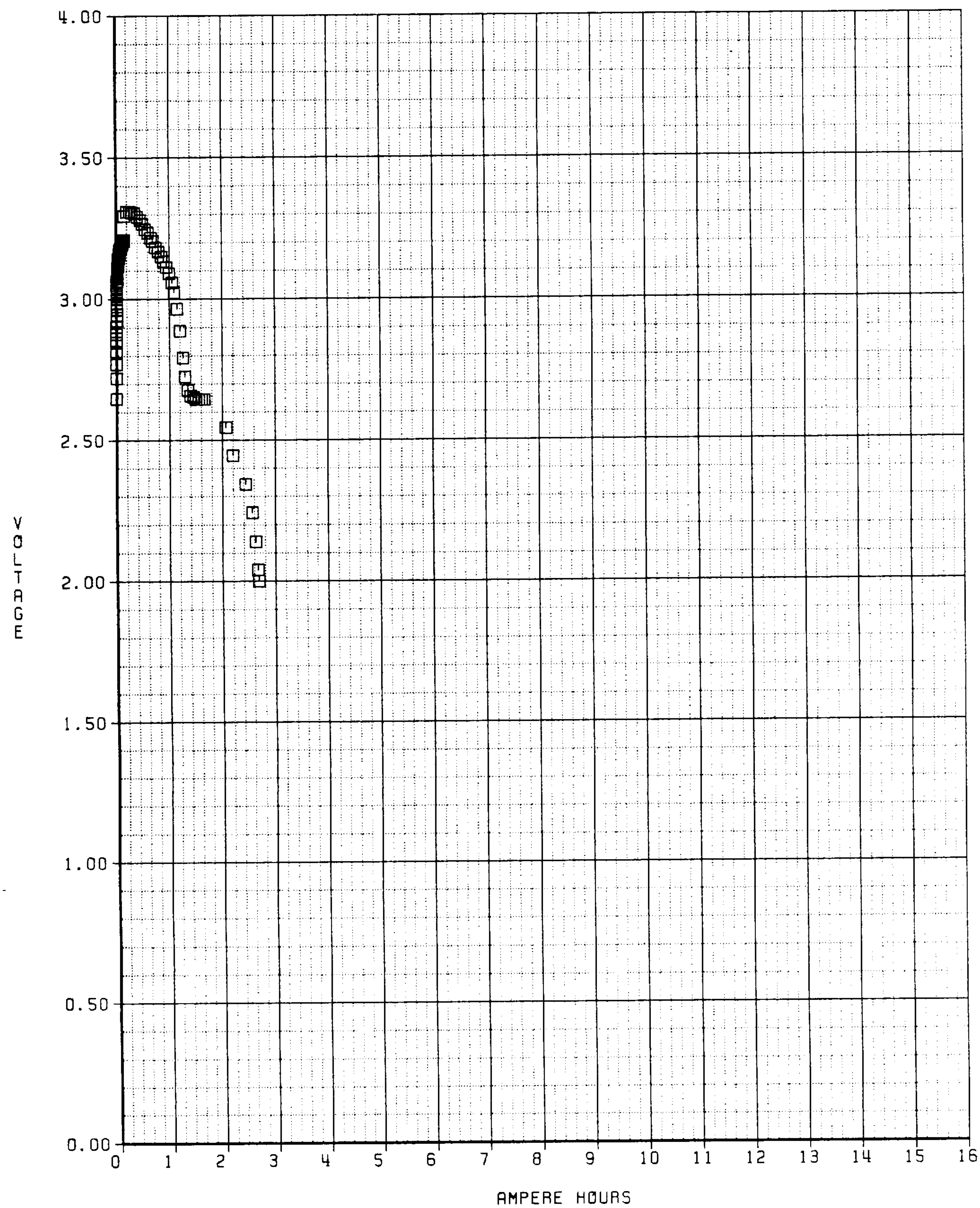
GPLOT(REV. 3.5)

DAY 062 WED, MAR 03 1993 09:39:10 AM

Figure 92

UNIV 0.6M LAC BCX D CELL
FRESH/3 AMP DISCHARGE AT -25°C

MACCOR3 ID 0452 OF NASA D CELL STUDY



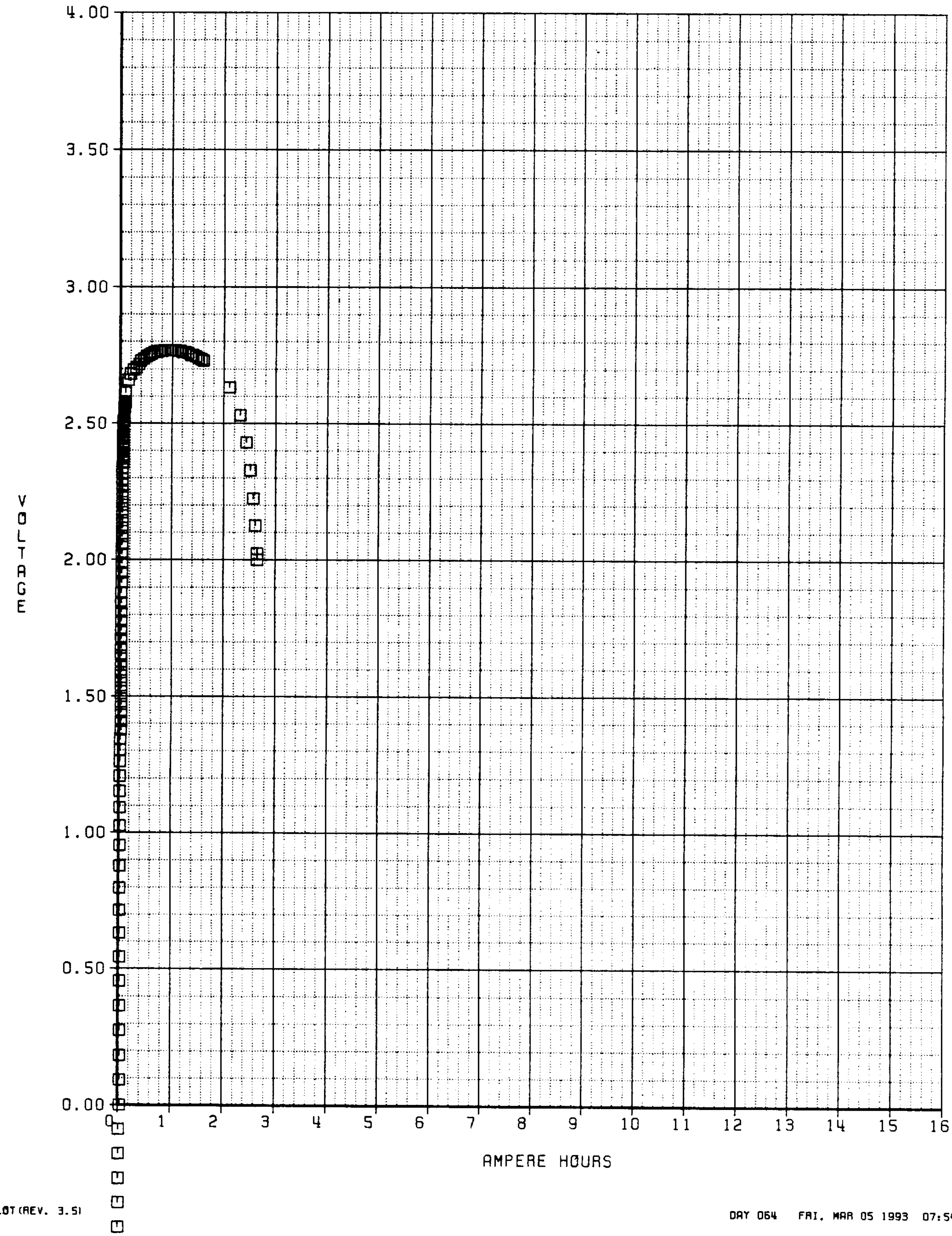
GPLOT(REV. 3.5)

DAY 064 FRI, MAR 05 1993 07:52:13 AM

Figure 93

UNIV 1.2M LAC TC D CELL
FRESH/3 AMP DISCHARGE AT -25⁰C

MACCOR3 ID 0455 OF NASA D CELL STUDY

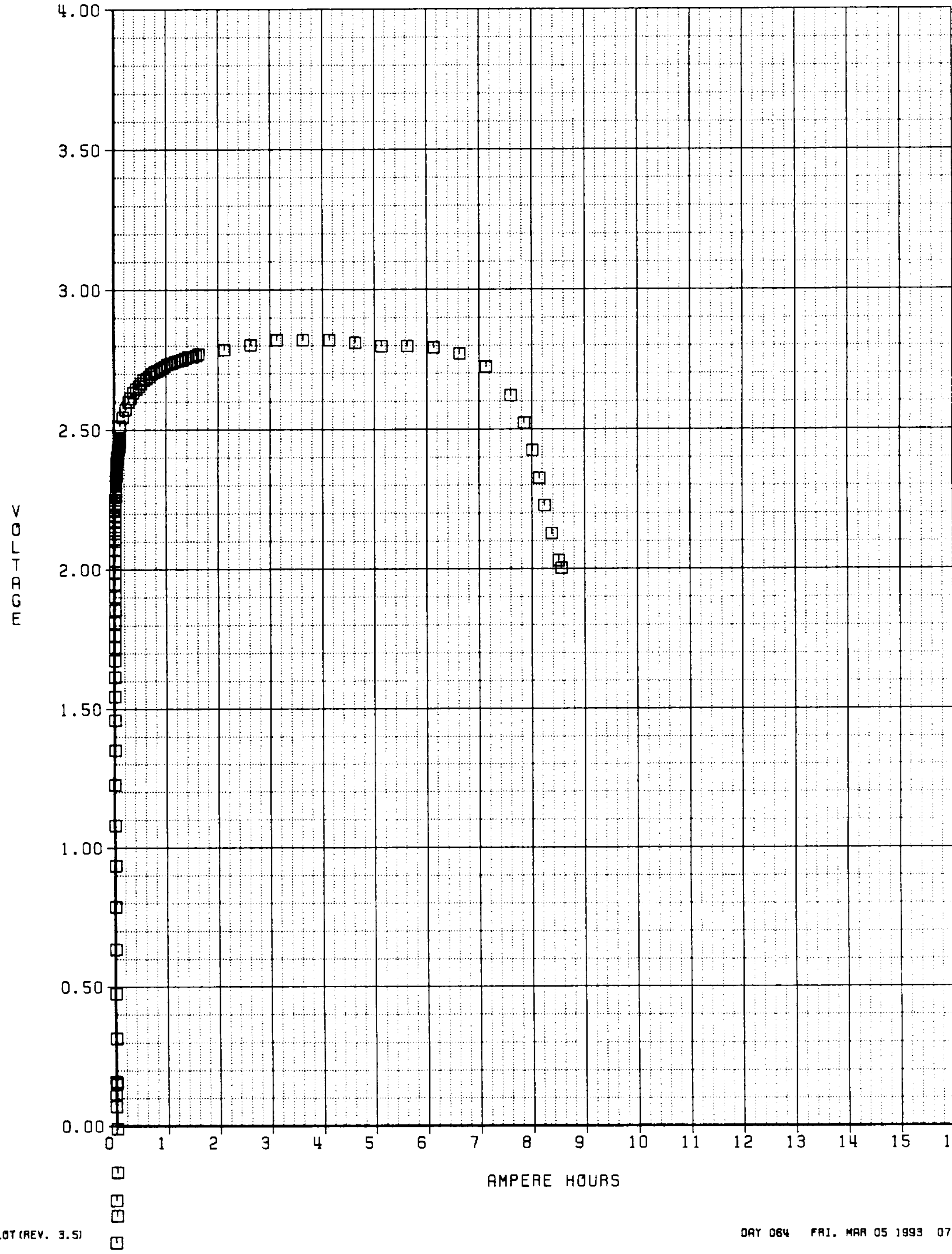


GPLOT (REV. 3.5)

DAY 064 FRI. MAR 05 1993 07:54:26 AM

Figure 94
UNIV 1.8M LAC CSC D CELL
FRESH/3 AMP DISCHARGE AT -25^{o}C

MACCOR3 ID 0459 OF NASA D CELL STUDY

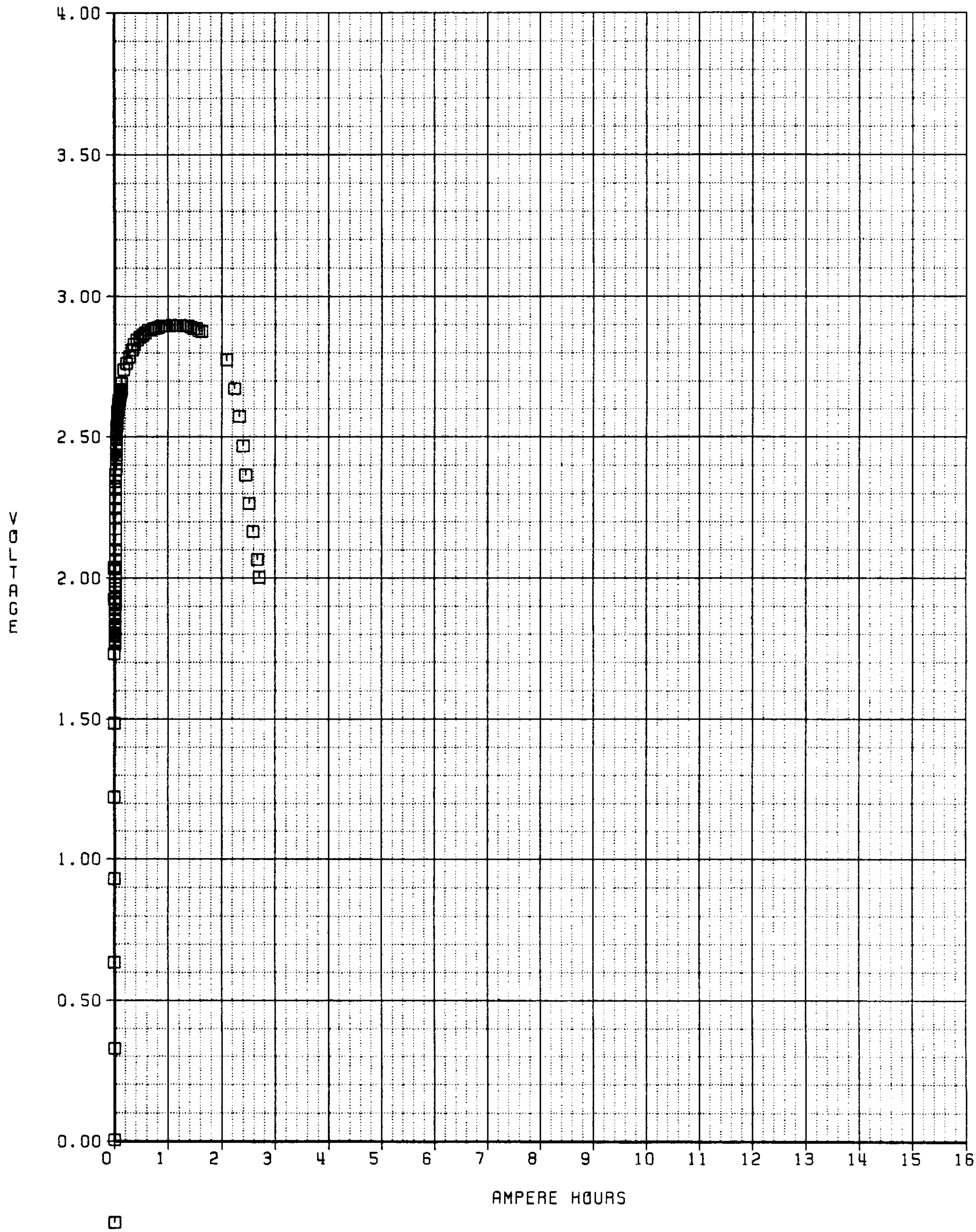


GPLOT(REV. 3.5)

DAY 064 FRI. MAR 05 1993 07:56:50 AM

Figure 95
JPL 1.8M LAC TC D CELL
FRESH/3 AMP DISCHARGE AT -25°C

MACCOR3 ID 0465 OF NASA D CELL STUDY



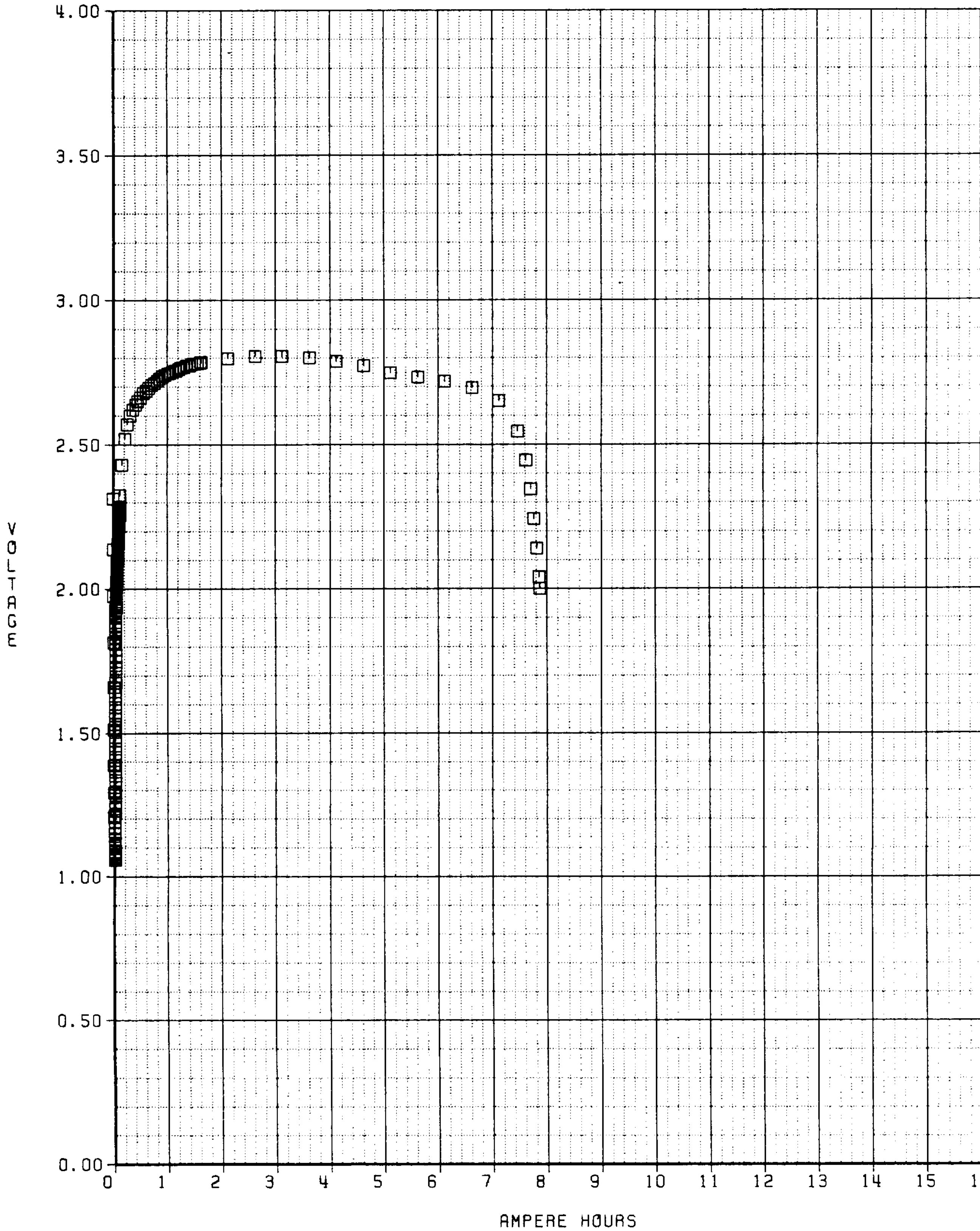
GPLOT(REV. 3.5)

DAY 064 FRI. MAR 05 1993 07:59:17 AM

Figure 96

JPL 0.6M LAC CSC D CELL
FRESH/3 AMP DISCHARGE AT -25ºC

MACCOR3 ID 0466 OF NASA D CELL STUDY



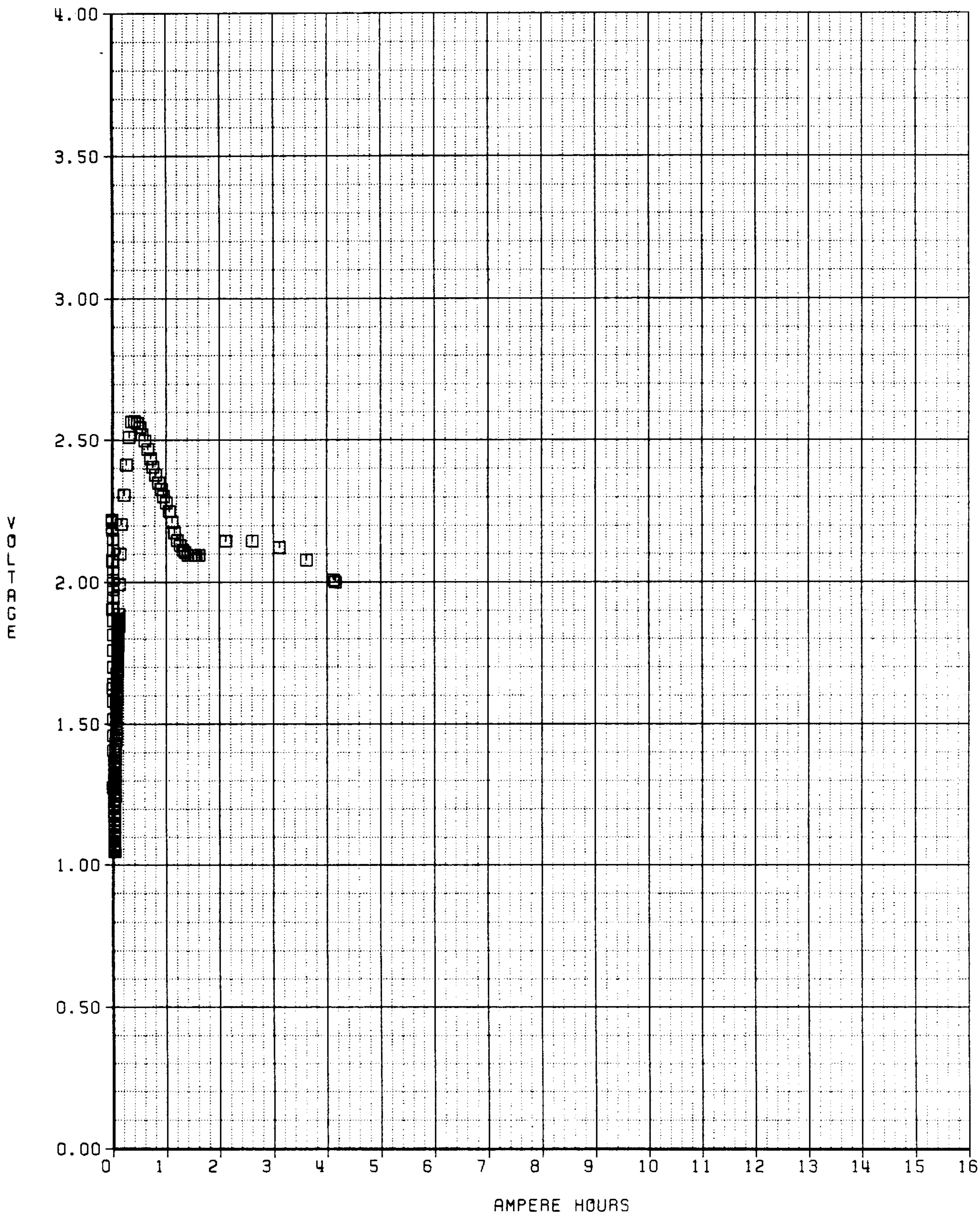
GPLOT (REV. 3.5)

DAY 064 FRI. MAR 05 1993 08:01:47 AM

Figure 97

NASA 1.8M LGC BCX D CELL
FRESH/3 AMP DISCHARGE AT -25°C

MACCOR3 ID 0469 OF NASA D CELL STUDY

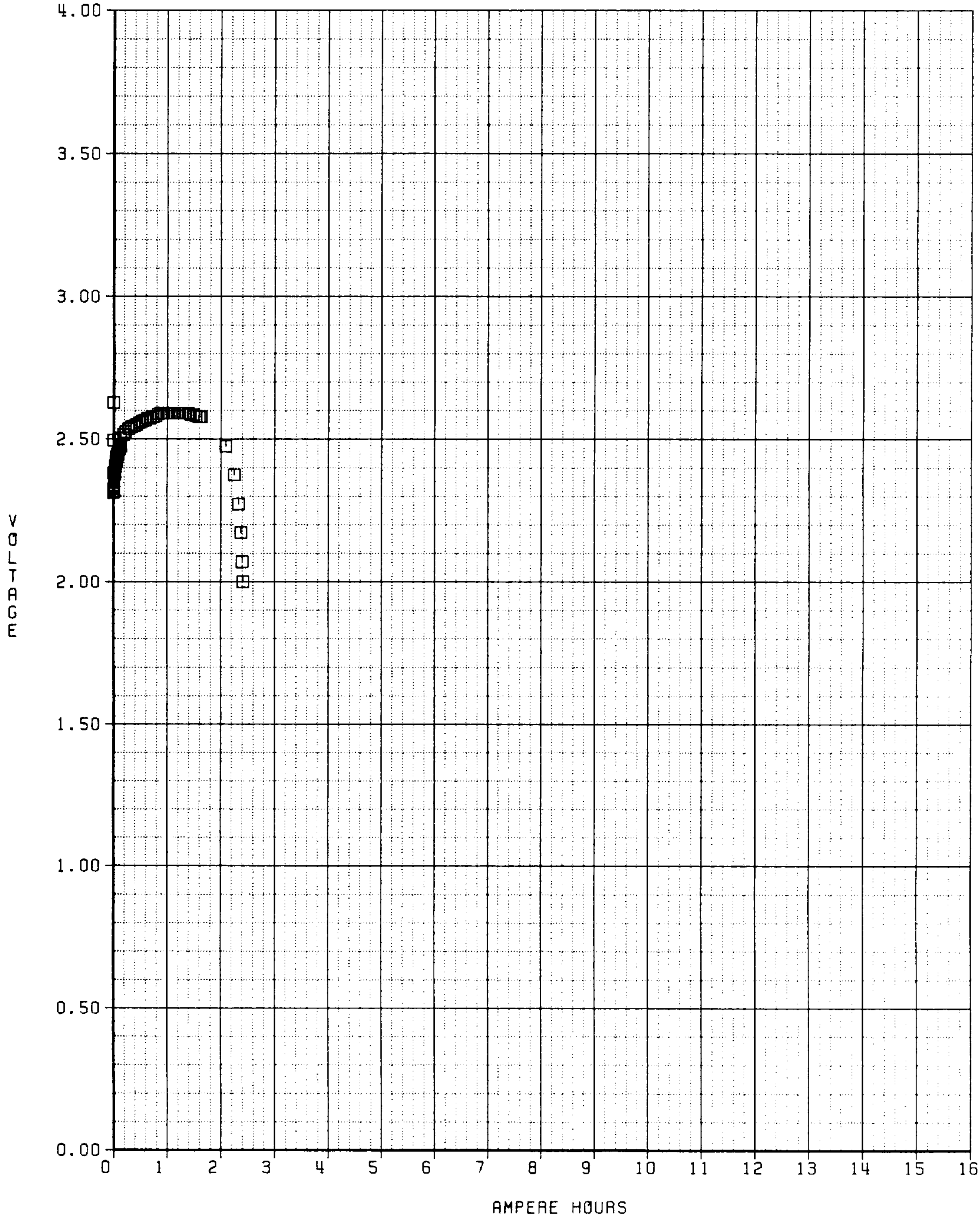


GPLOT(REV. 3.5) DAY 068 TUE, MAR 09 1993 3:39:56 PM

Figure 98

NASA 0.6M LGC TC D CELL
FRESH/3 AMP DISCHARGE AT -25°C

MACCOR3 ID 0473 OF NASA D CELL STUDY

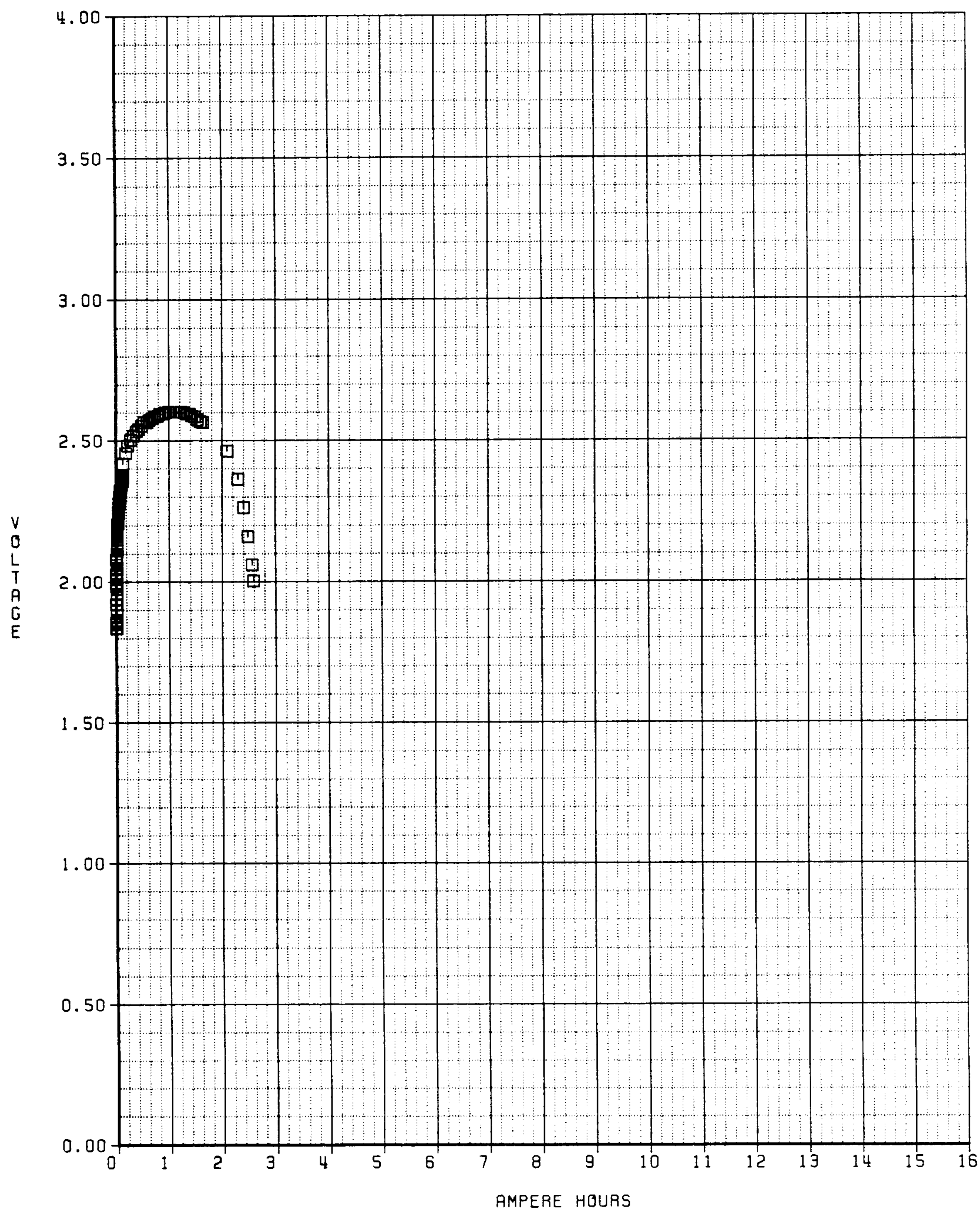


GPLOT (REV. 3.5) DAY 061 TUE, MAR 02 1993 3:59:08 PM

Figure 99

NASA 1.2M LGC CSC D CELL
FRESH/3 AMP DISCHARGE AT $-25^{0}C$

MACCOR3 ID 0476 OF NASA D CELL STUDY



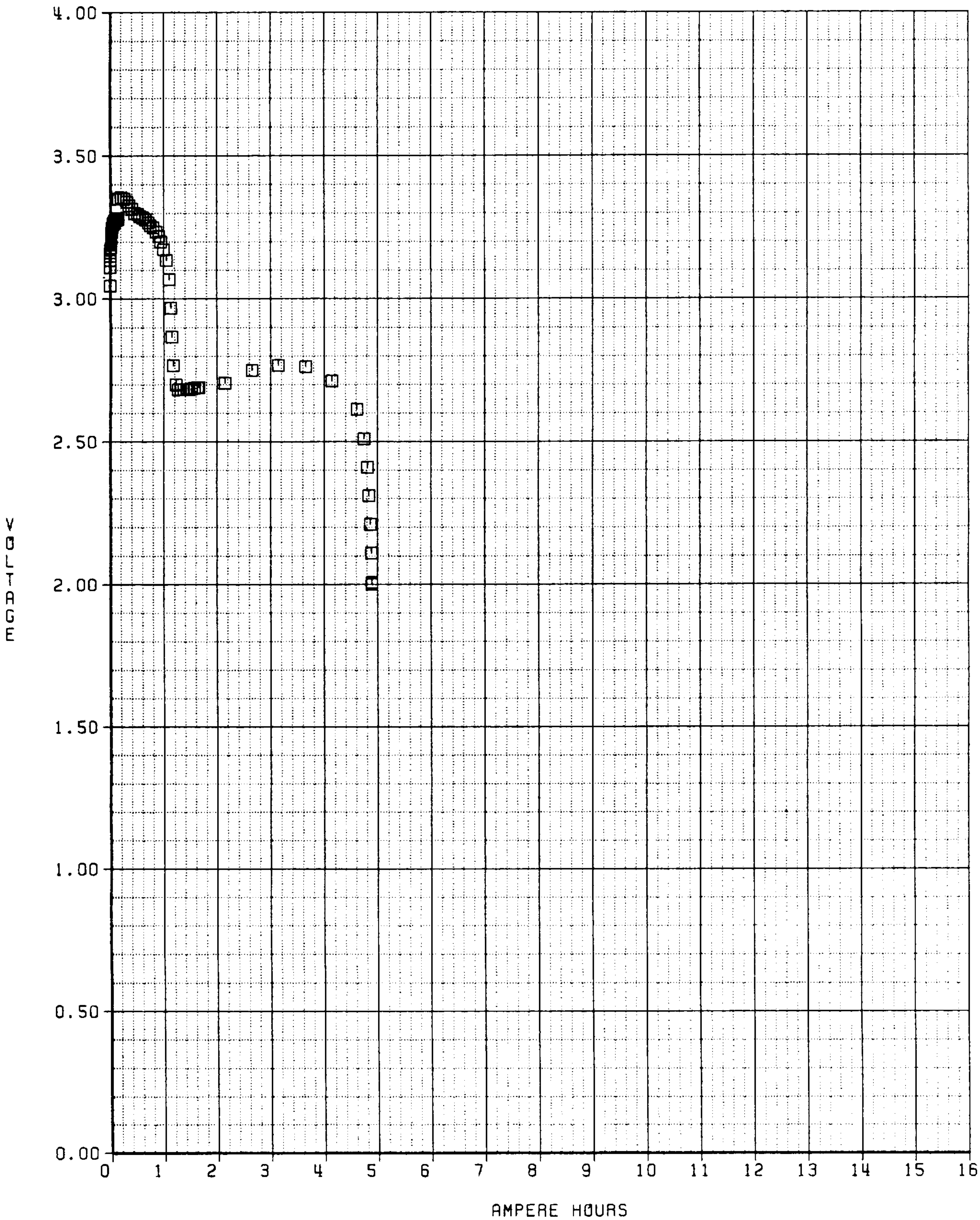
GPLOT(REV. 3.5)

DAY 061 TUE. MAR 02 1993 3:55:04 PM

Figure 100

UNIV 1.2M LGC BCX D CELL
FRESH/3 AMP DISCHARGE AT -25°C

MACCOR3 ID 0480 OF NASA D CELL STUDY

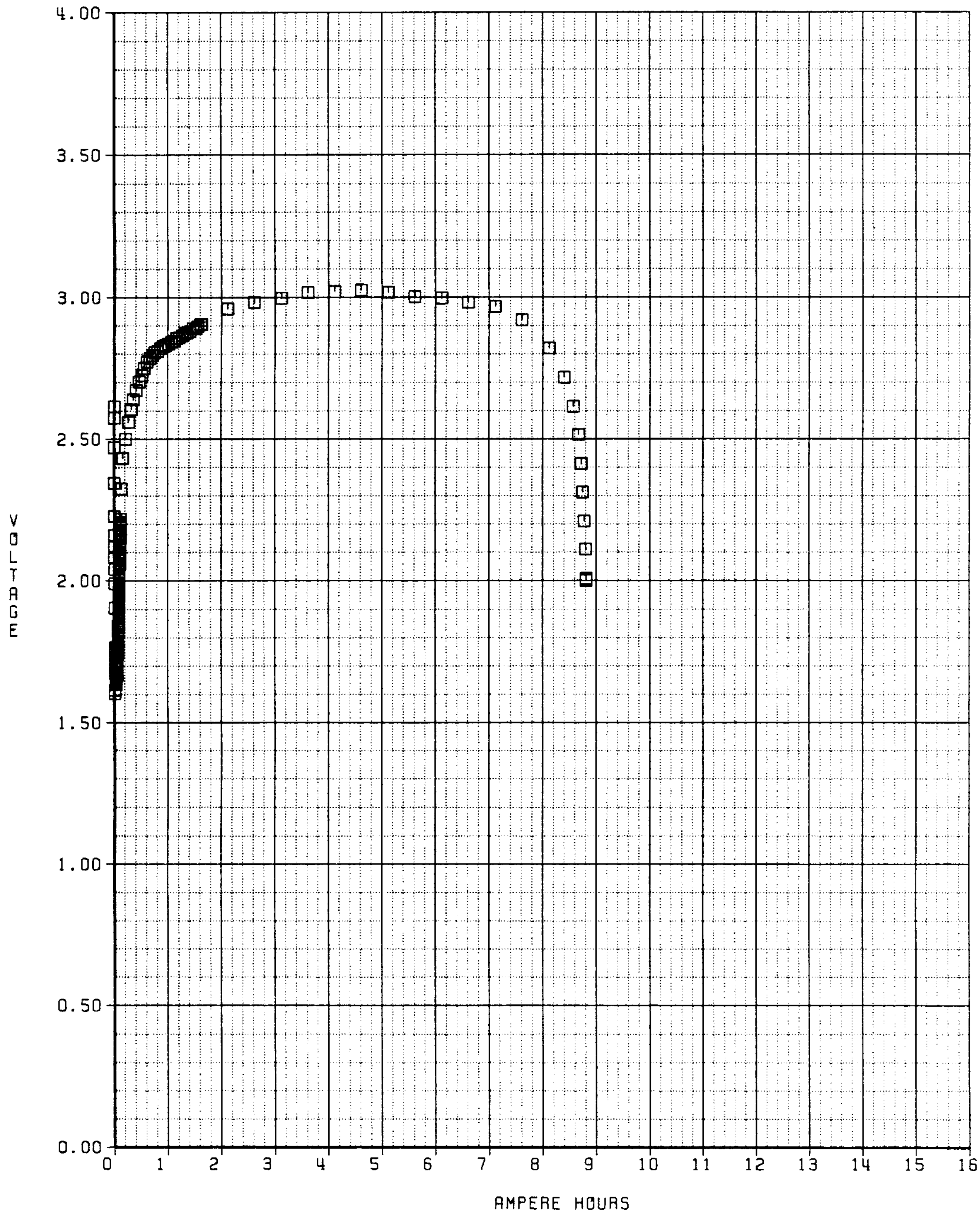


GPLOT(REV. 3.5)   DAY 061   TUE. MAR 02 1993   3:37:33 PM

Figure 101

UNIV 1.8M LGC TC D CELL
FRESH/3 AMP DISCHARGE AT -25°C

MACCOR3 ID 0482 OF NASA D CELL STUDY



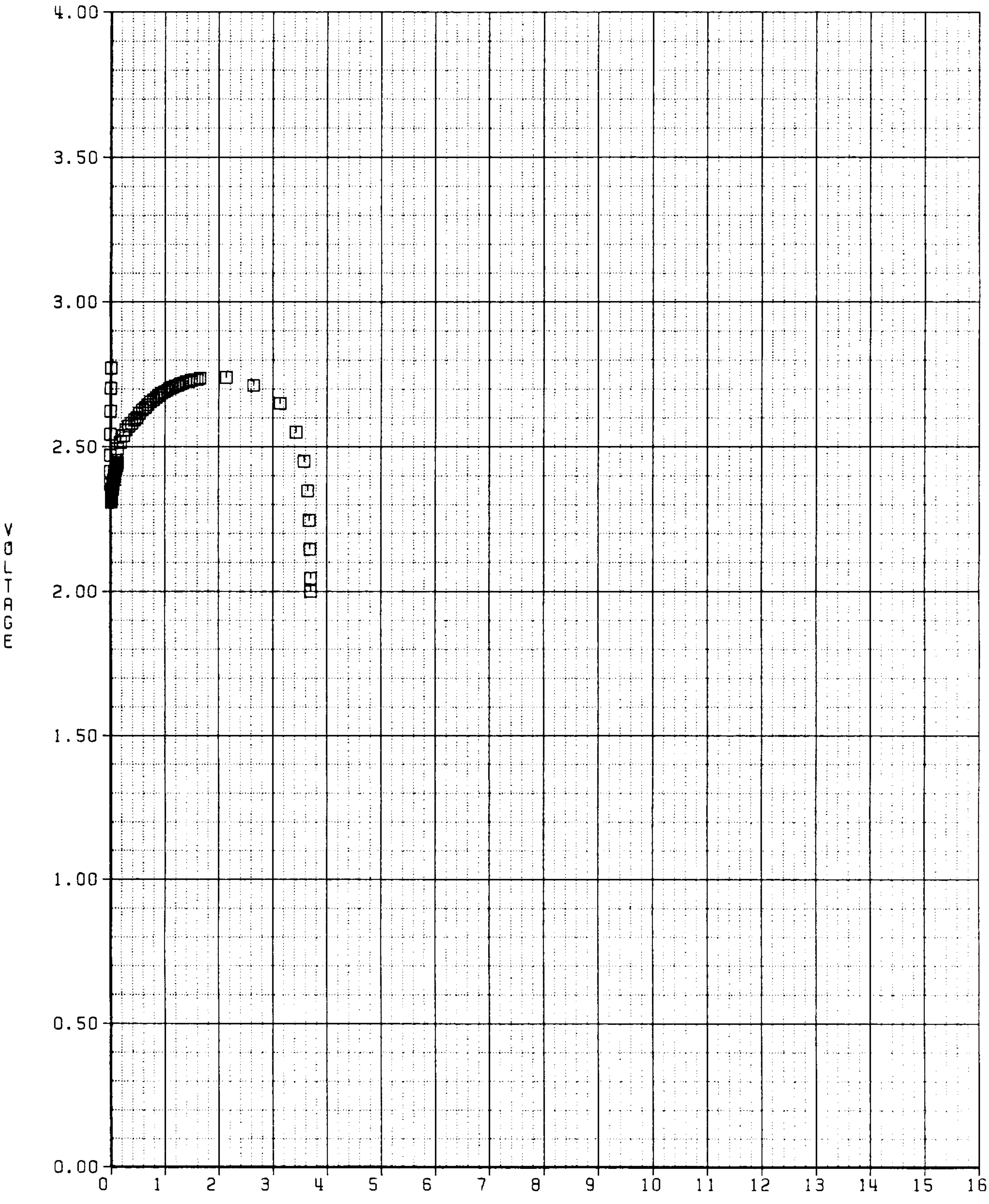
GPLOT(REV. 3.5)

DAY 061 TUE. MAR 02 1993 10:04:40 AM

Figure 102

UNIV 0.6M LGC CSC D CELL
FRESH/3 AMP DISCHARGE AT -25°C

MACCOR3 ID 0484 OF NASA D CELL STUDY



GPLOT(REV. 3.5)

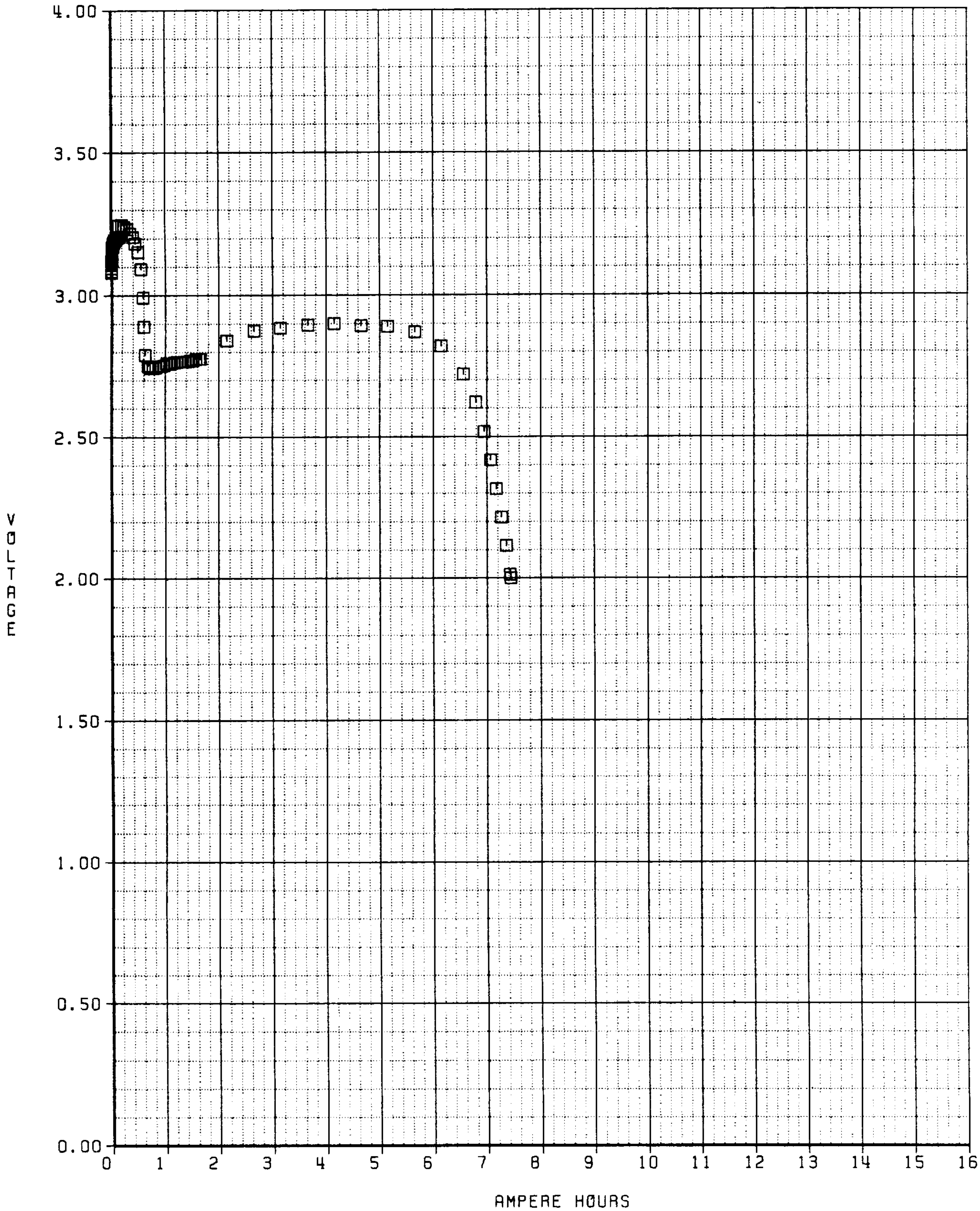
DAY 061 TUE, MAR 02 1993 09:51:53 AM

Figure 103

JPL 1.8M LGC BCX D CELL

FRESH/3 AMP DISCHARGE AT RT

MACCOR3 ID 0488 OF NASA D CELL STUDY



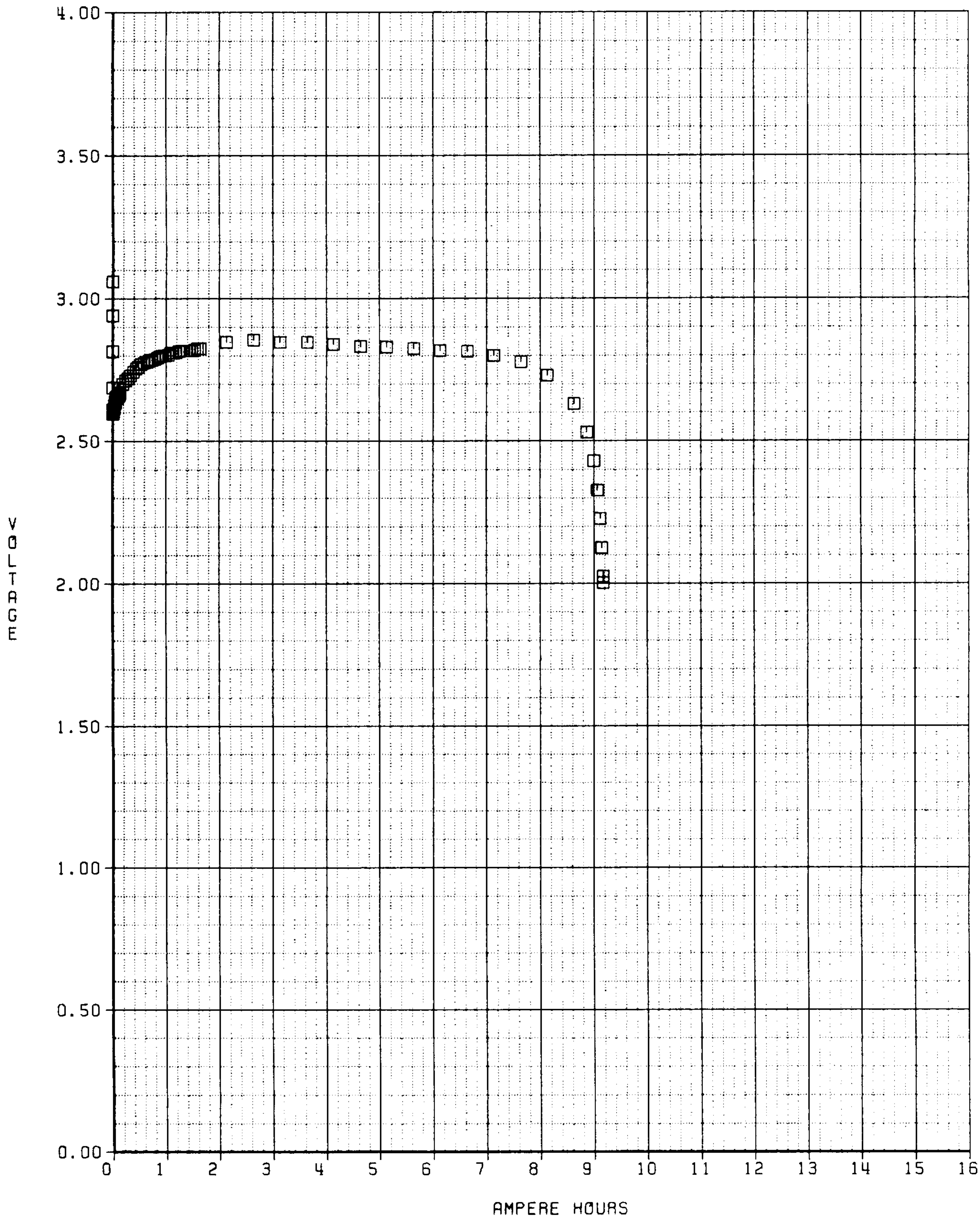
GPLOT(REV. 3.5)

DAY 058 SAT, FEB 27 1993 11:41:23 AM

Figure 104

JPL 0.6M LGC TC D CELL
FRESH/3 AMP DISCHARGE AT RT

MACCOR3 ID 0492 OF NASA D CELL STUDY



GPLOT(REV. 3.5)

DAY 058 SAT. FEB 27 1993 11:56:55 AM

Figure 105

JPL 1.2M LGC CSC D CELL
FRESH/3 AMP DISCHARGE AT RT

MACCOR3 ID 0495 OF NASA D CELL STUDY

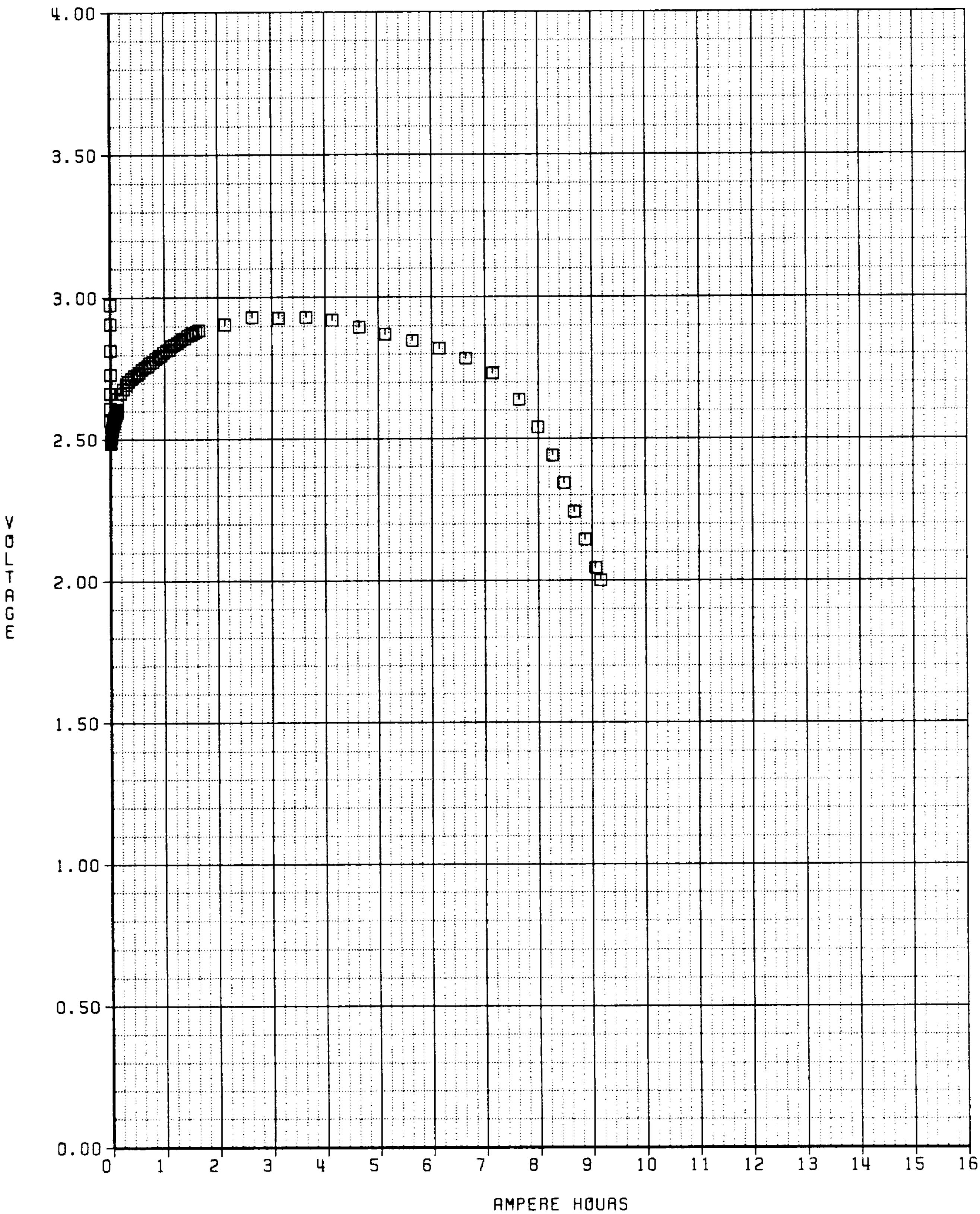


Figure 106

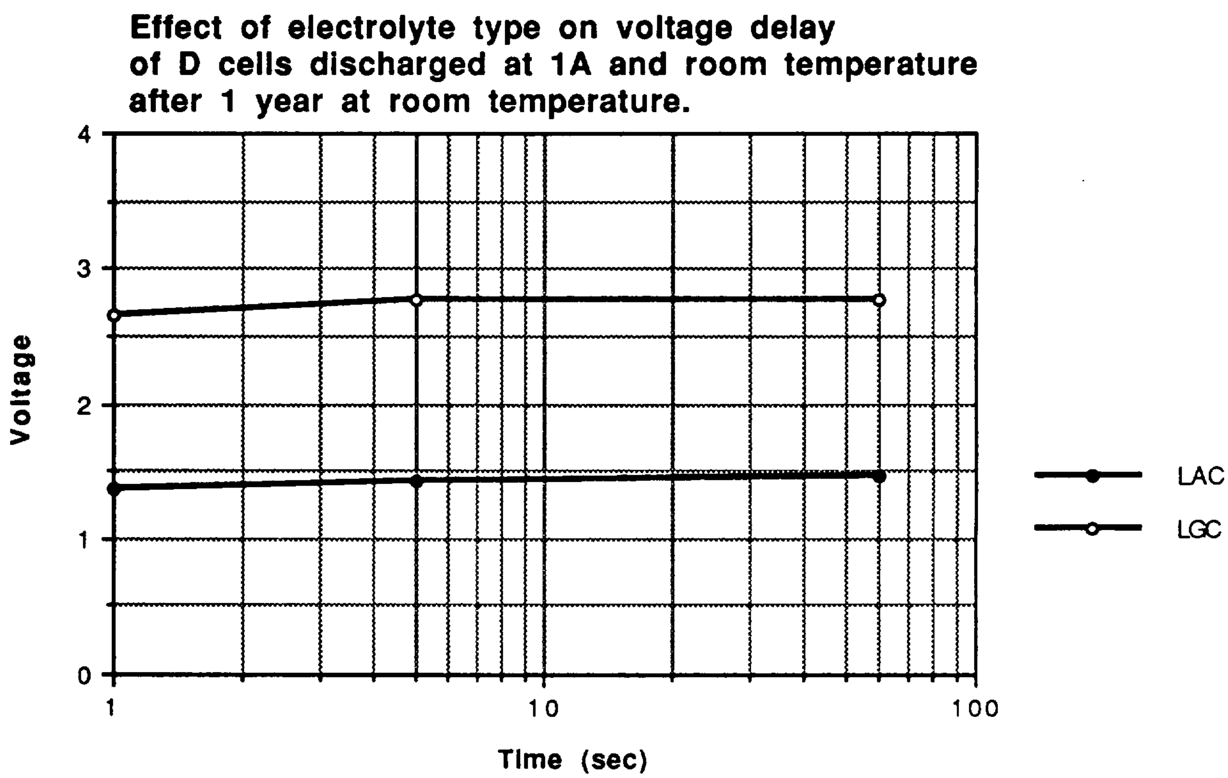

Effect of electrolyte type on voltage delay
of D cells discharged at 1A and room temperature
after 1 year at room temperature.
4
3
2
1
0
Voltage
1
10
100
Time (sec)
LAC
LGC

Figure 107

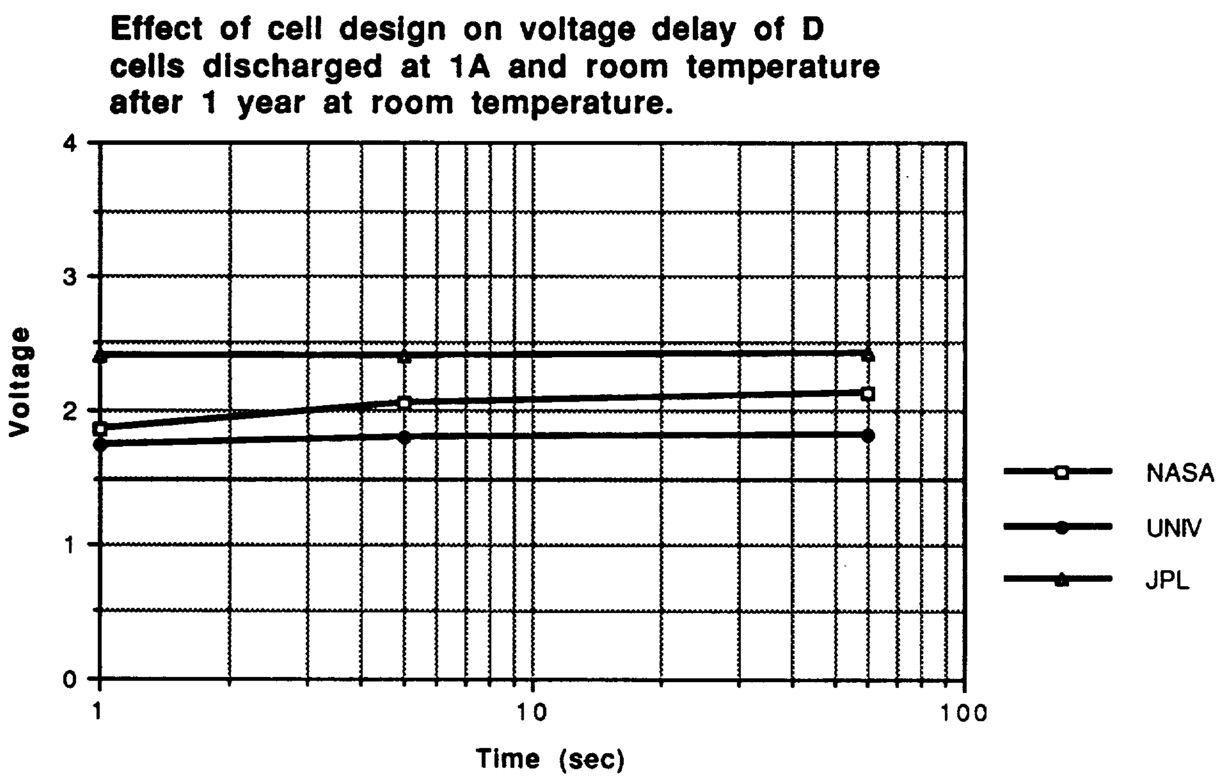
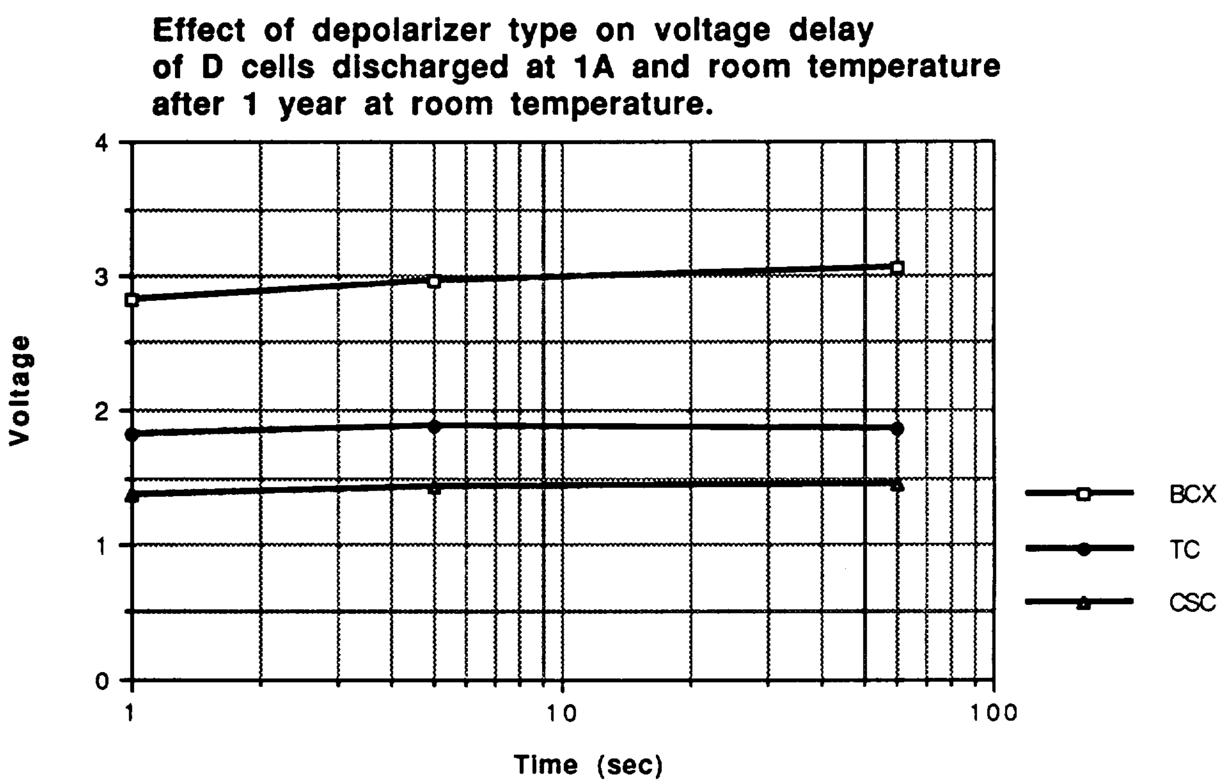

Effect of cell design on voltage delay of D cells discharged at 1A and room temperature after 1 year at room temperature.
Voltage
0
1
2
3
4
1
10
100
Time (sec)
NASA
UNIV
JPL

Figure 108



Effect of depolarizer type on voltage delay
of D cells discharged at 1A and room temperature
after 1 year at room temperature.
Voltage
4
3
2
1
0
1
10
100
Time (sec)
BCX
TC
CSC

Figure 109

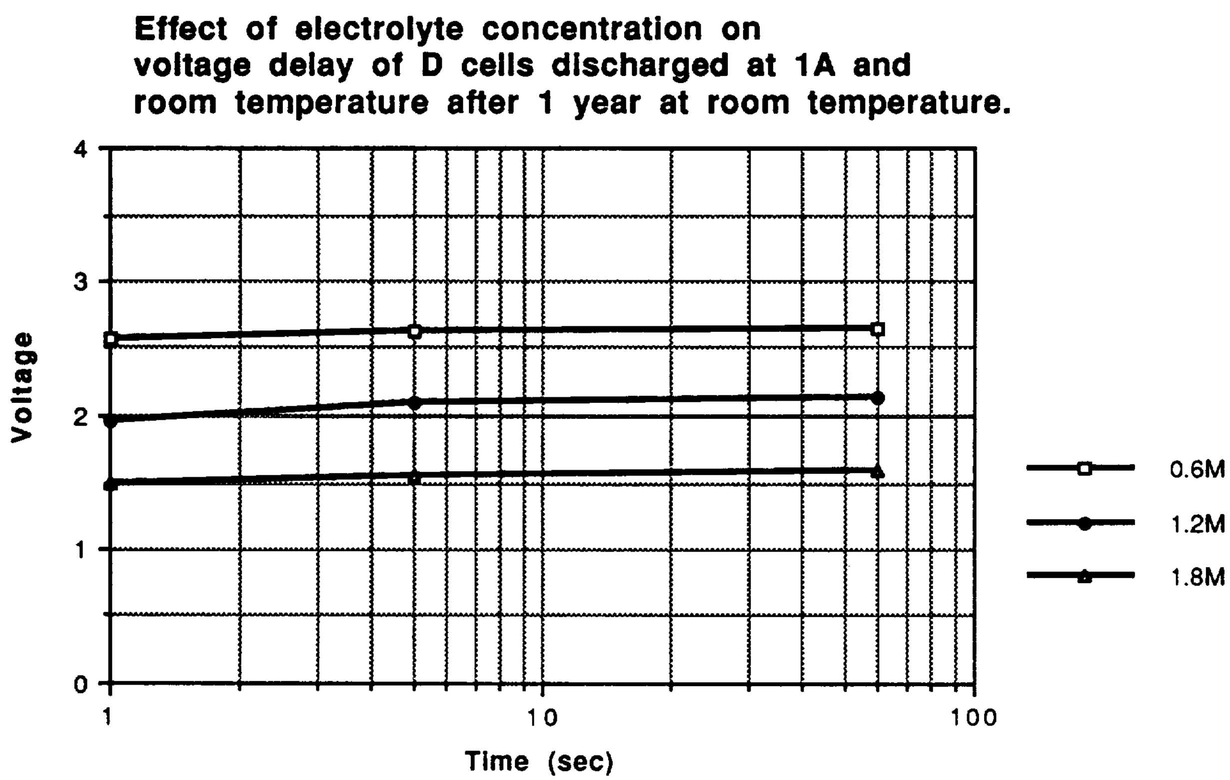

Effect of electrolyte concentration on
voltage delay of D cells discharged at 1A and
room temperature after 1 year at room temperature.
Voltage
4
3
2
1
0
1
10
100
Time (sec)
0.6M
1.2M
1.8M

Figure 110

Effect of electrolyte type on running voltage of D cells discharged at 1A and room temperature after 1 year at room temperature.

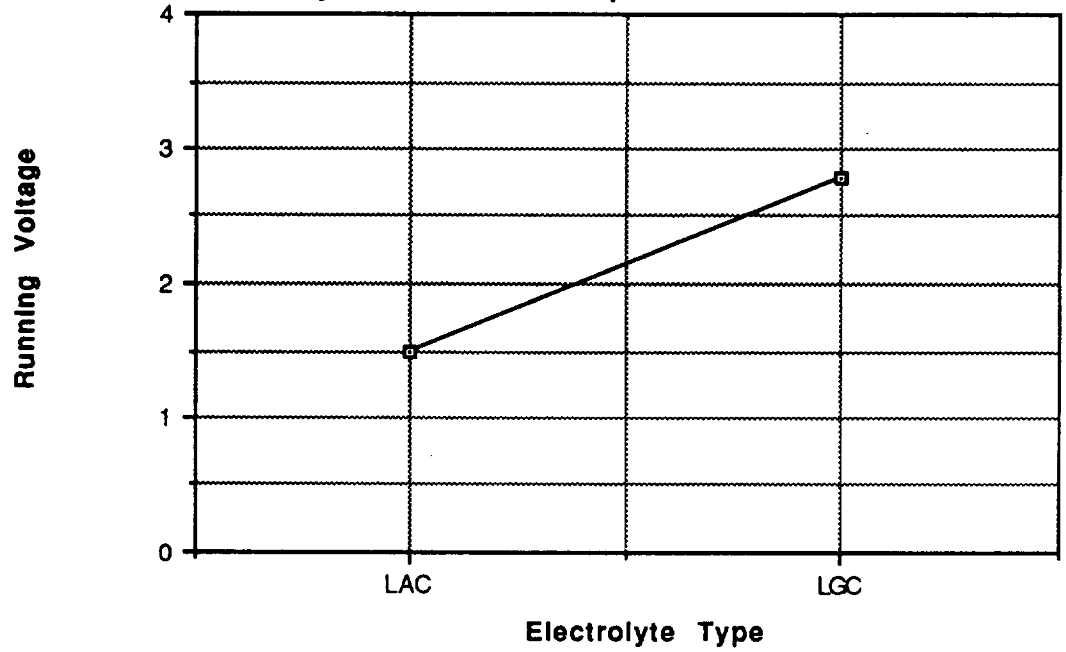


Figure 111

Effect of cell design on running voltage of D cells discharged at 1A and room temperature after 1 year at room temperature.

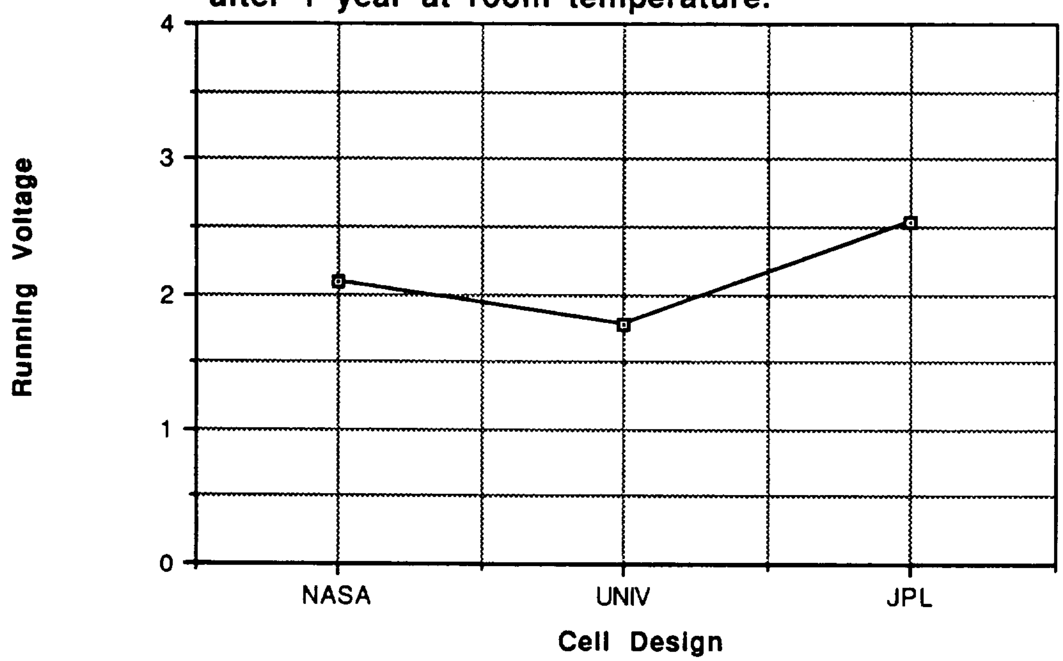


Figure 112

Effect of depolarizer type on running voltage of D cells discharged at 1A and room temperature after 1 year at room temperature.

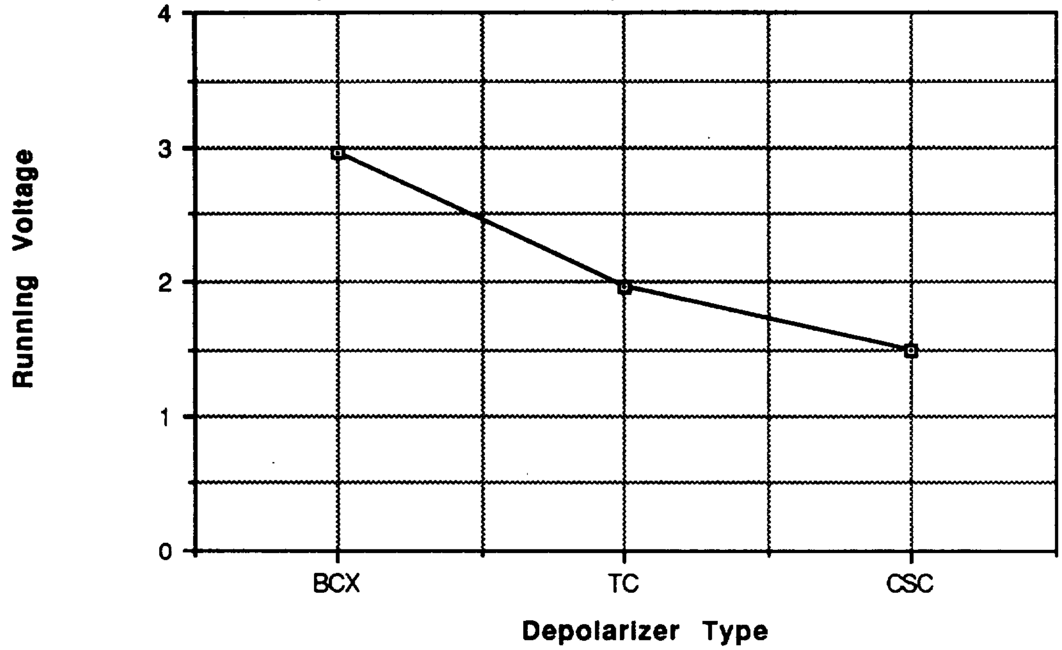


Figure 113

Effect of electrolyte concentration on running voltage of D cells discharged at 1A and room temperature after 1 year at room temperature.

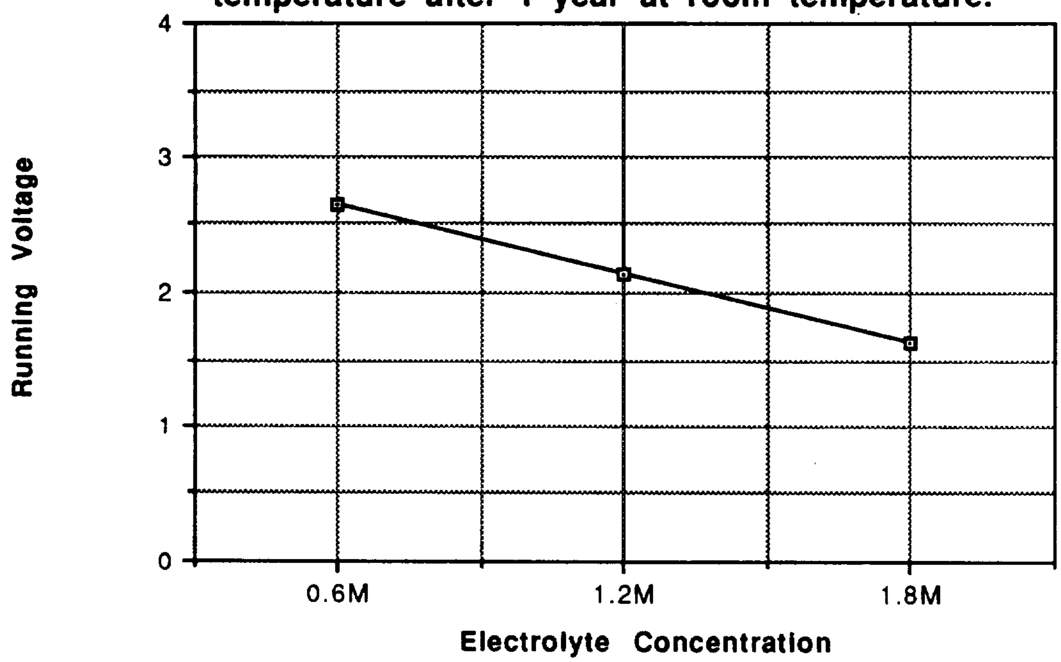


Figure 114

Effect of electrolyte type on capacity of D cells discharged at 1A and room temperature after 1 year at room temperature.

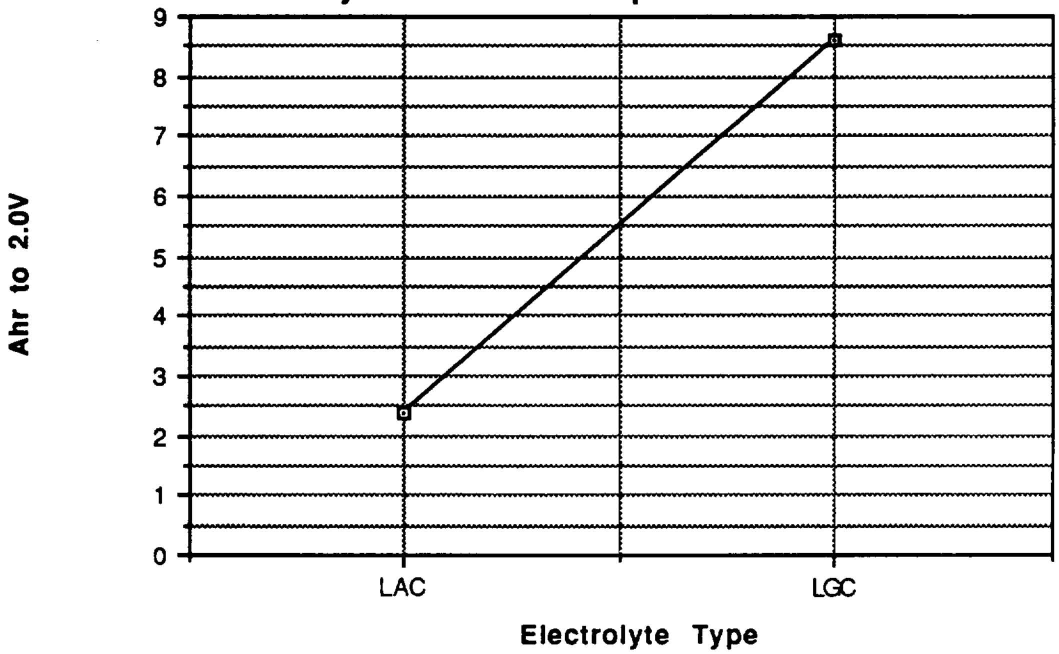


Figure 115

Effect of cell design on capacity of D cells discharged at 1A and room temperature after 1 year at room temperature.

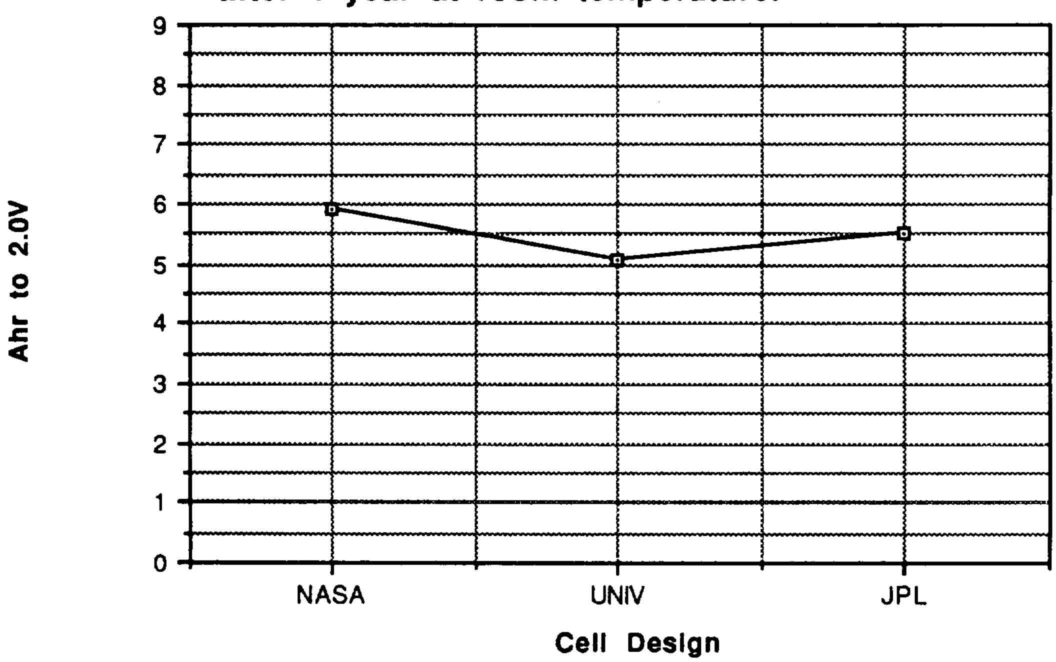


Figure 116

Effect of depolarizer type on capacity of D cells discharged at 1A and room temperature after 1 year at room temperature.

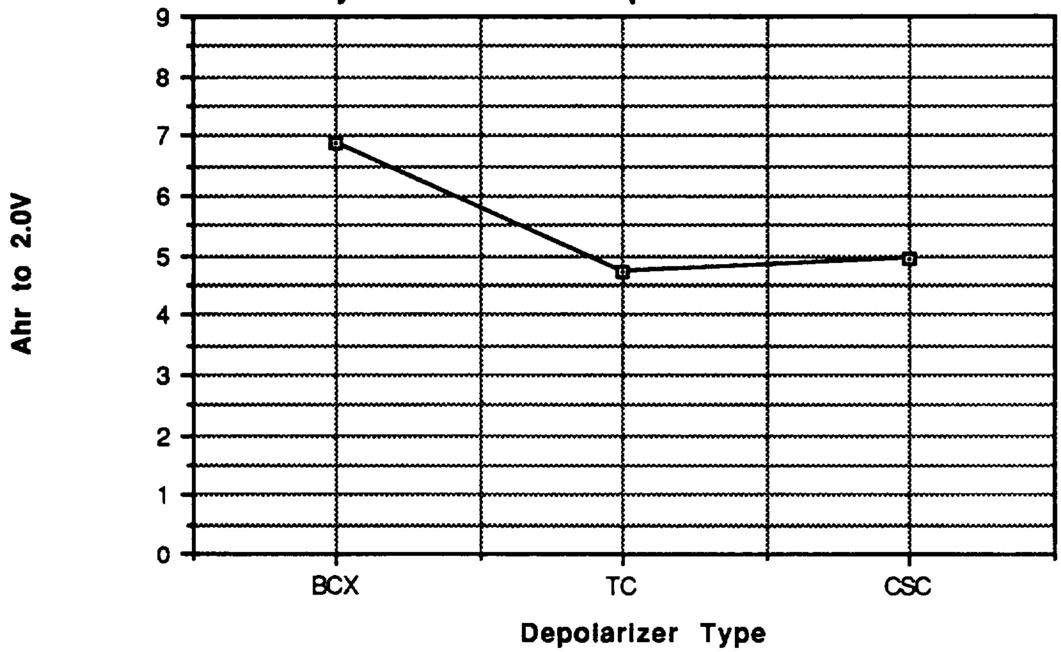
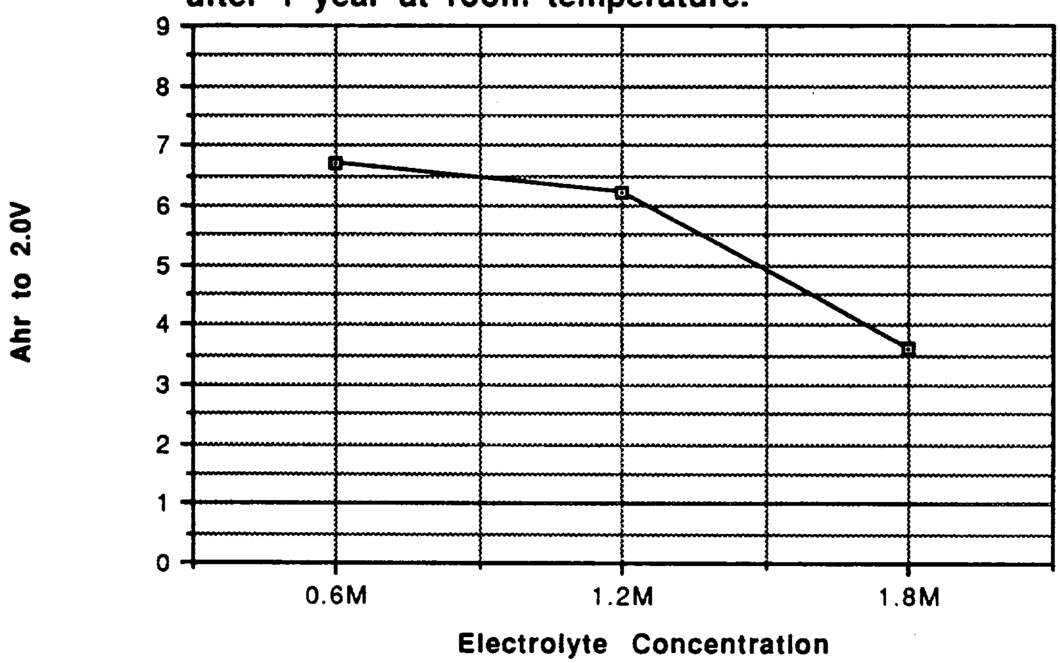


Figure 117

Effect of electrolyte concentration on capacity of D cells discharged at 1A and room temperature after 1 year at room temperature.



expressed in percent capacity retention. The electrolyte salt had the largest effect on capacity retention (38.3% of the variation) and the cells with LGC electrolyte retained an average of 80.7% of their initial capacity, compared to 32.5% for cells with LAC electrolyte. This difference is largely due to the fact that the 14 cells containing LAC electrolyte which could not start up under the 1A load were assessed as having zero capacity at this rate. The cell design did not affect capacity retention and the depolarizer and electrolyte concentration each accounted for 8.9% of the variation in capacity retention. Figures 118 - 121 illustrate the effects of the four factors on capacity retention.

Figures 122 - 133 are representative discharge curves for the cells discharged at 1A and room temperature after 1 year at room temperature. Six of the eighteen groups had all three cells fail under this test regimen and therefore have no discharge curves. The ANOVA reports for the 6 performance attributes are contained in Appendix F.

5.6 3A ROOM TEMPERATURE PERFORMANCE AFTER 1 YEAR

Fifty four D cells were discharged under 3A at room temperature after 1 year storage at room temperature. Under these conditions 21 cells failed to operate, and 16 of these cells were those containing LAC electrolyte. The electrolyte type had the largest effect on start up voltage accounting for 19 - 24.5% of the variation in voltage recovery. Figure 134 shows that cells with LGC electrolyte recover to 2.4V in 1 second compared to a 1 second voltage of 0.98V for cells with LAC electrolyte. The remaining three factors are small contributors to voltage recovery, and their main effects are illustrated in figures 135 - 137. As seen under the previous test conditions, the JPL design provides a small advantage,and BCX depolarizer and low molarity electrolyte both aid in voltage recovery to some degree.

The running voltage is also affected by the electrolyte type which accounts for 20.9% of the variation in voltage at 50% DOD. Figure 138 shows that cells with LGC electrolyte have operating voltages of 2.47V compared to operating voltages of 1.11V for cells with LAC electrolyte. The JPL design offers higher operating voltages than the other 2 designs, and accounts for 10.8% of the variation in performance. (See figure 139). The depolarizer type and the electrolyte concentration play a slight role in determining the running voltage under these conditions. However, the BCX depolarizer and the low molarity electrolyte are favored. (See figures 140 & 141).

The electrolyte type and the cell design are the main factors affecting capacity at this rate, temperature and storage period. The electrolyte accounts for 29.3% and the cell design accounts

Figure 118

Effect of electrolyte type on capacity retention of D cells discharged at 1A and room temperature after 1 year at room temperature.

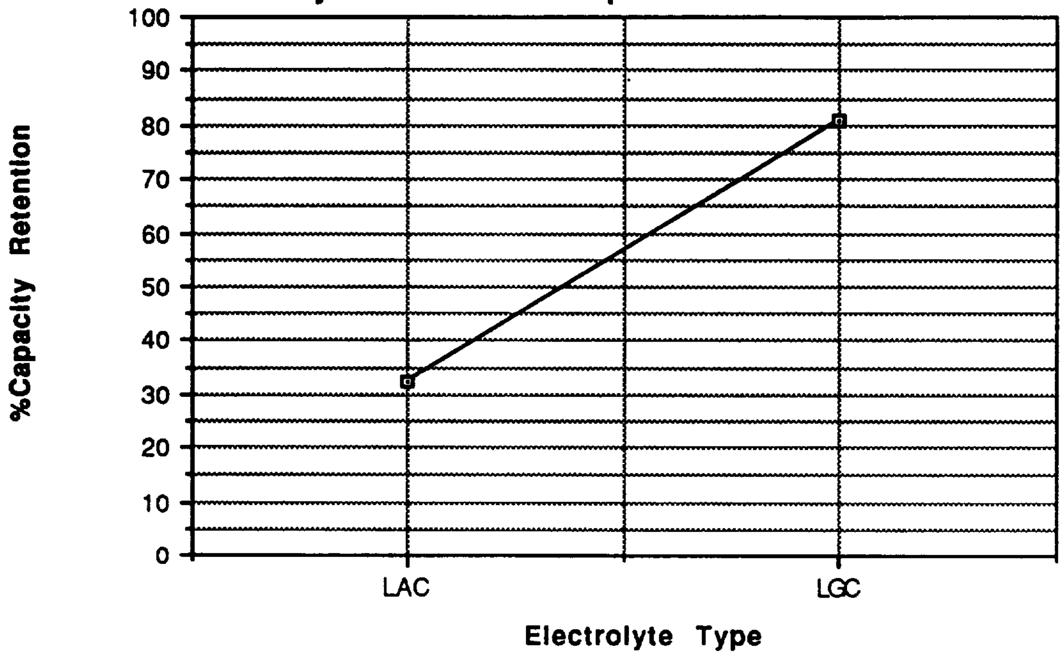


Figure 119

Effect of cell design on capacity retention of D cells discharged at 1A and room temperature after 1 year at room temperature.

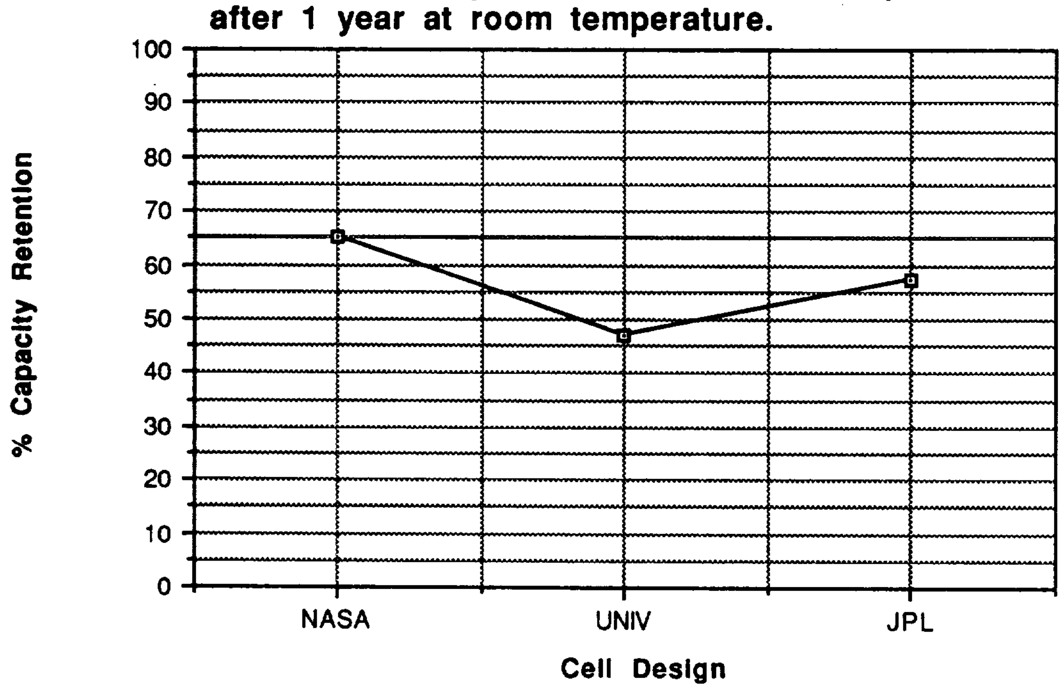


Figure 120

Effect of depolarizer type on capacity retention of D cells discharged at 1A and room temperature after 1 year at room temperature.

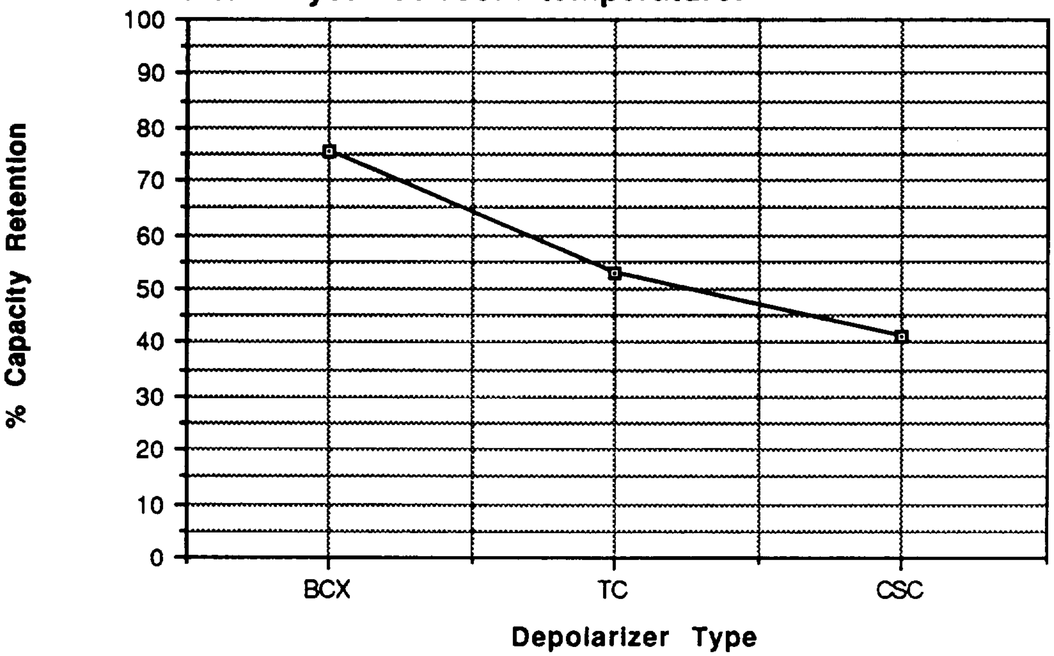


Figure 121

Effect of electrolyte concentration on capacity retention of D cells discharged at 1A and room temperature after 1 year at room temperature.

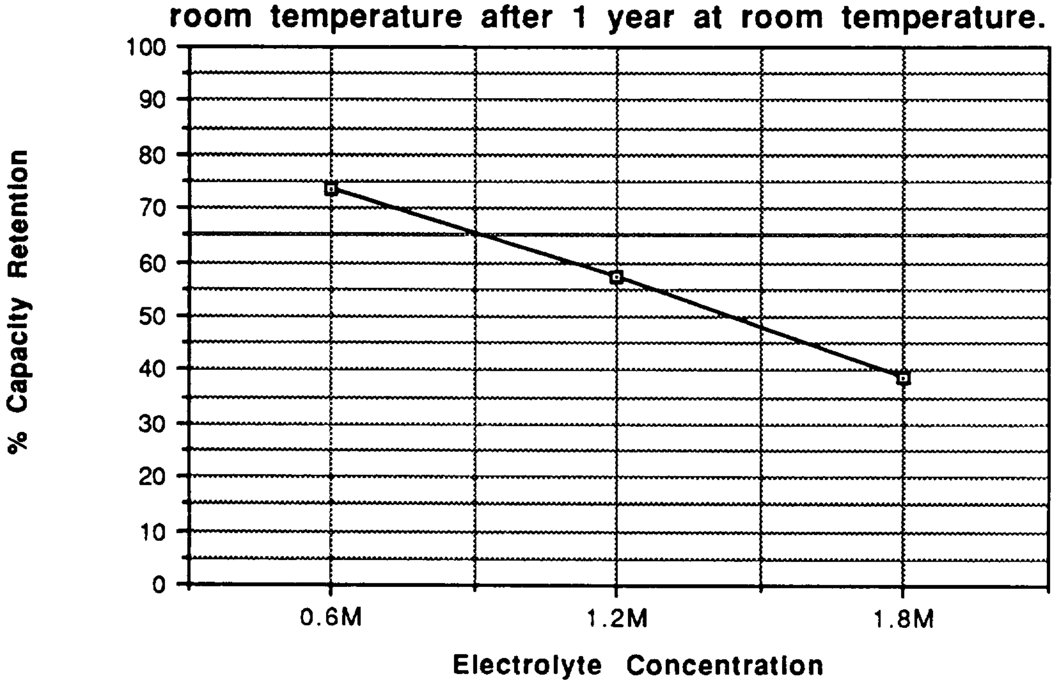


Figure 122

NASA 0.6M LAC BCX D CELL
1 YEAR STORAGE AT AM TEMP/1 AMP DISCHARGE AT AT

MACCOR3 ID 1231 OF NASA D CELL STUDY

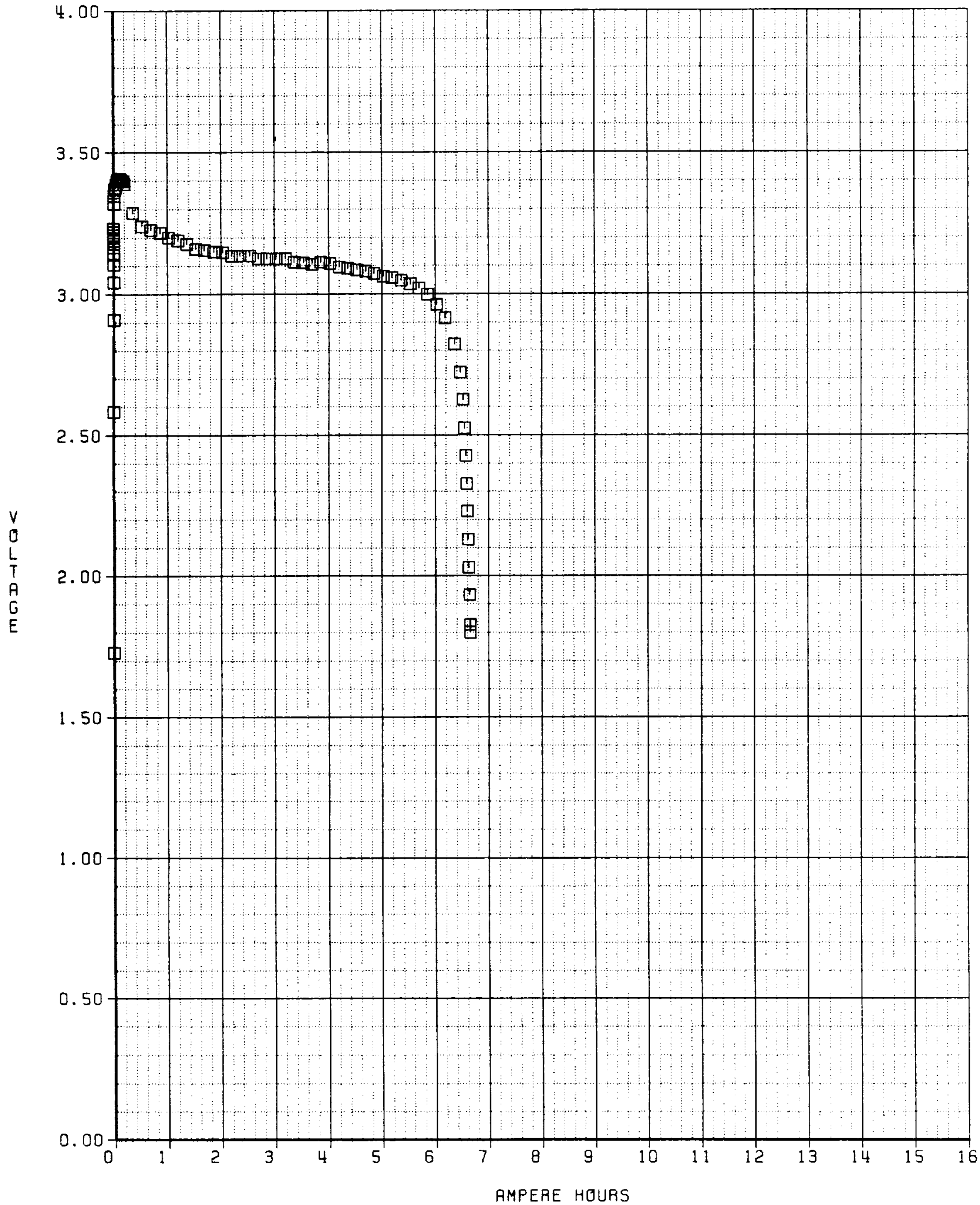


Figure 123
UNIV 0.6M LAC BCX D CELL
1 YR STORAGE AT RM TEMP/1 AMP DISCHARGE AT RT

MACCOR3 ID 1238 OF NASA D CELL STUDY

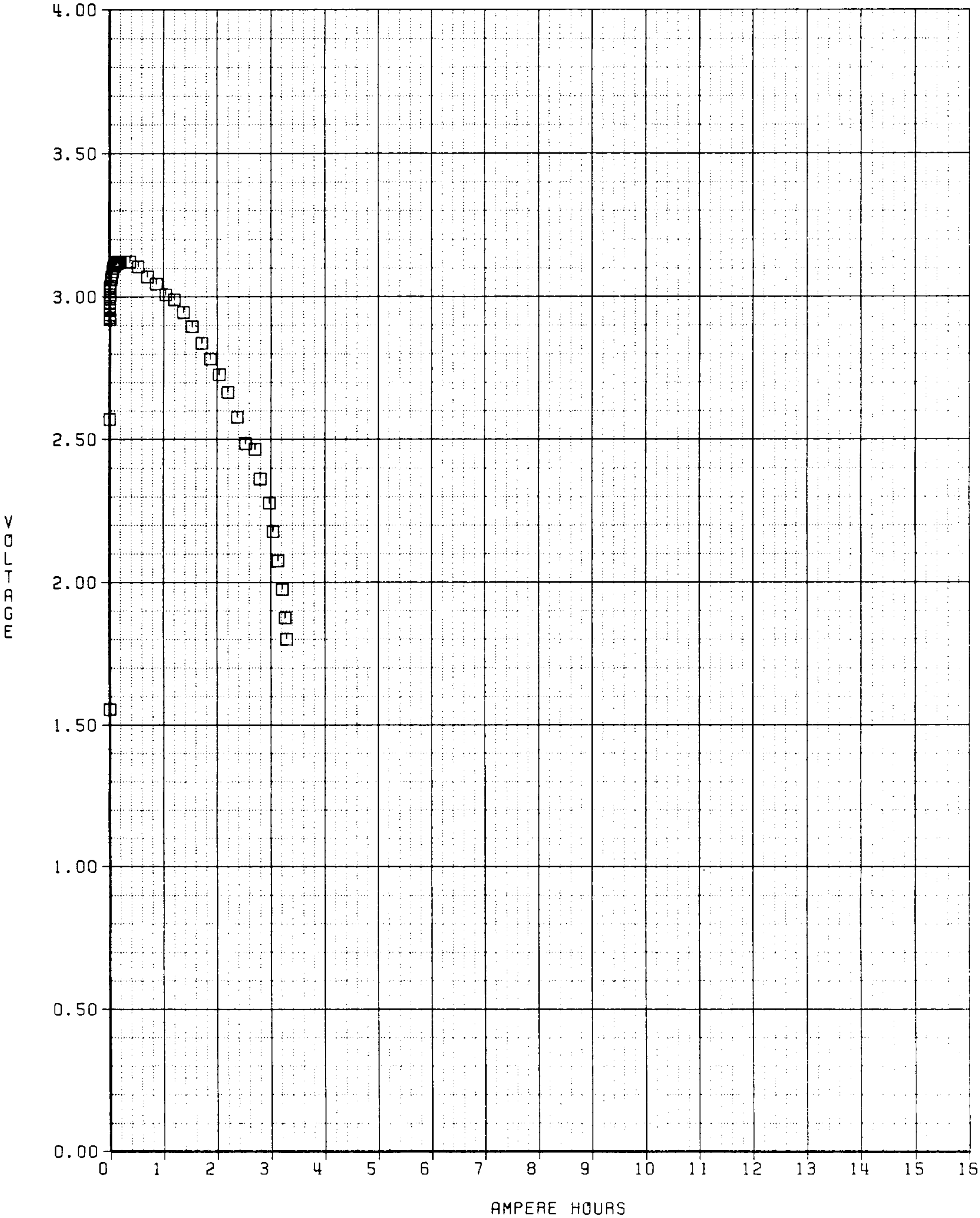


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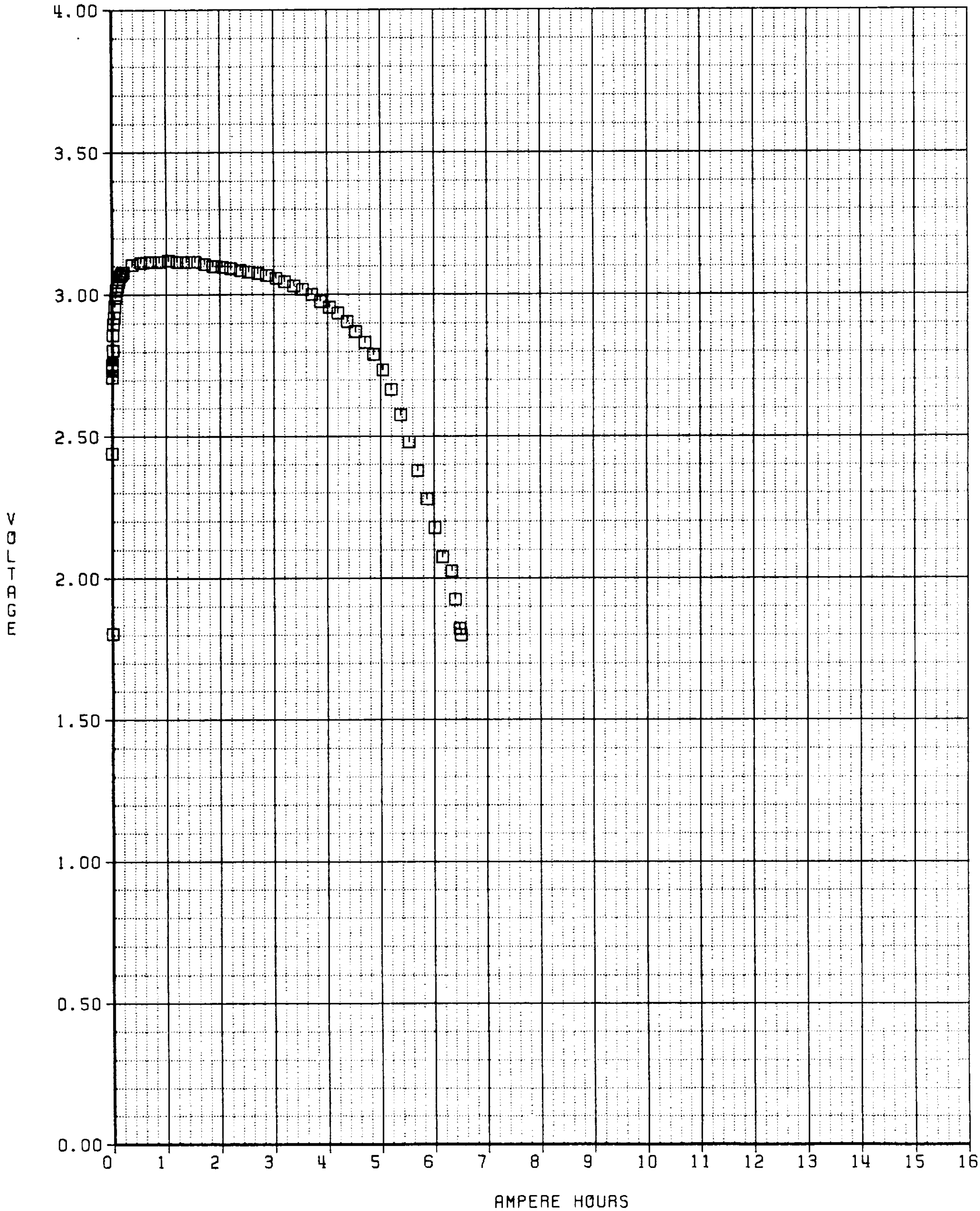
Figure 124

JPL 1.2M LAC BCX D CELL
1 YR STORAGE AT RM TEMP/1 AMP DISCHARGE AT RT

MACCOR3 ID 1248 OF NASA D CELL STUDY



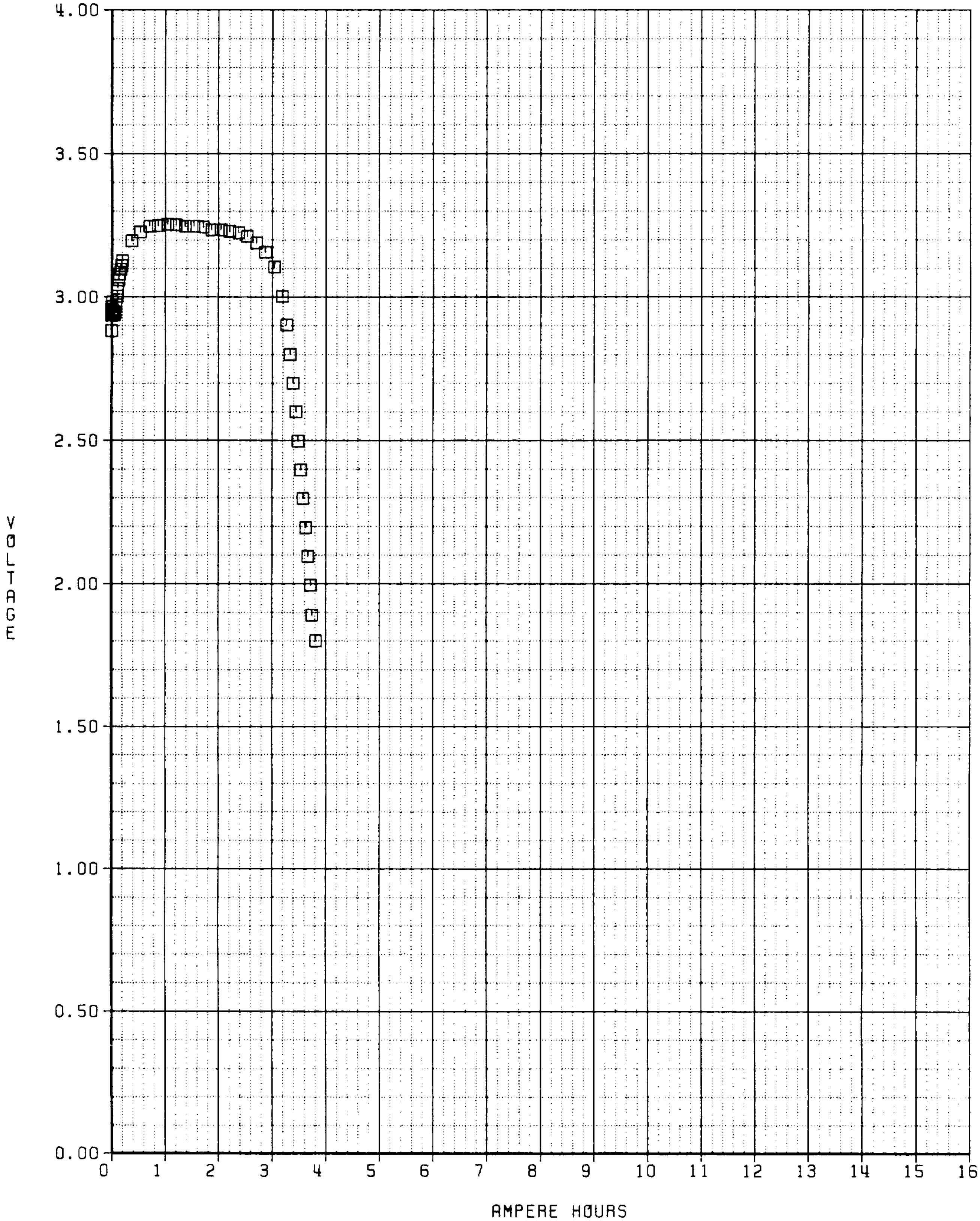
GPLOT(REV. 3.5)

DAY 054 TUE, FEB 23 1993 11:55:38 AM

Figure 125

JPL 1.8M LAC TC D CELL
1 YR STORAGE AT RM TEMP/1 AMP DISCHARGE AT RT

MACCOR3 ID 1250 OF NASA D CELL STUDY



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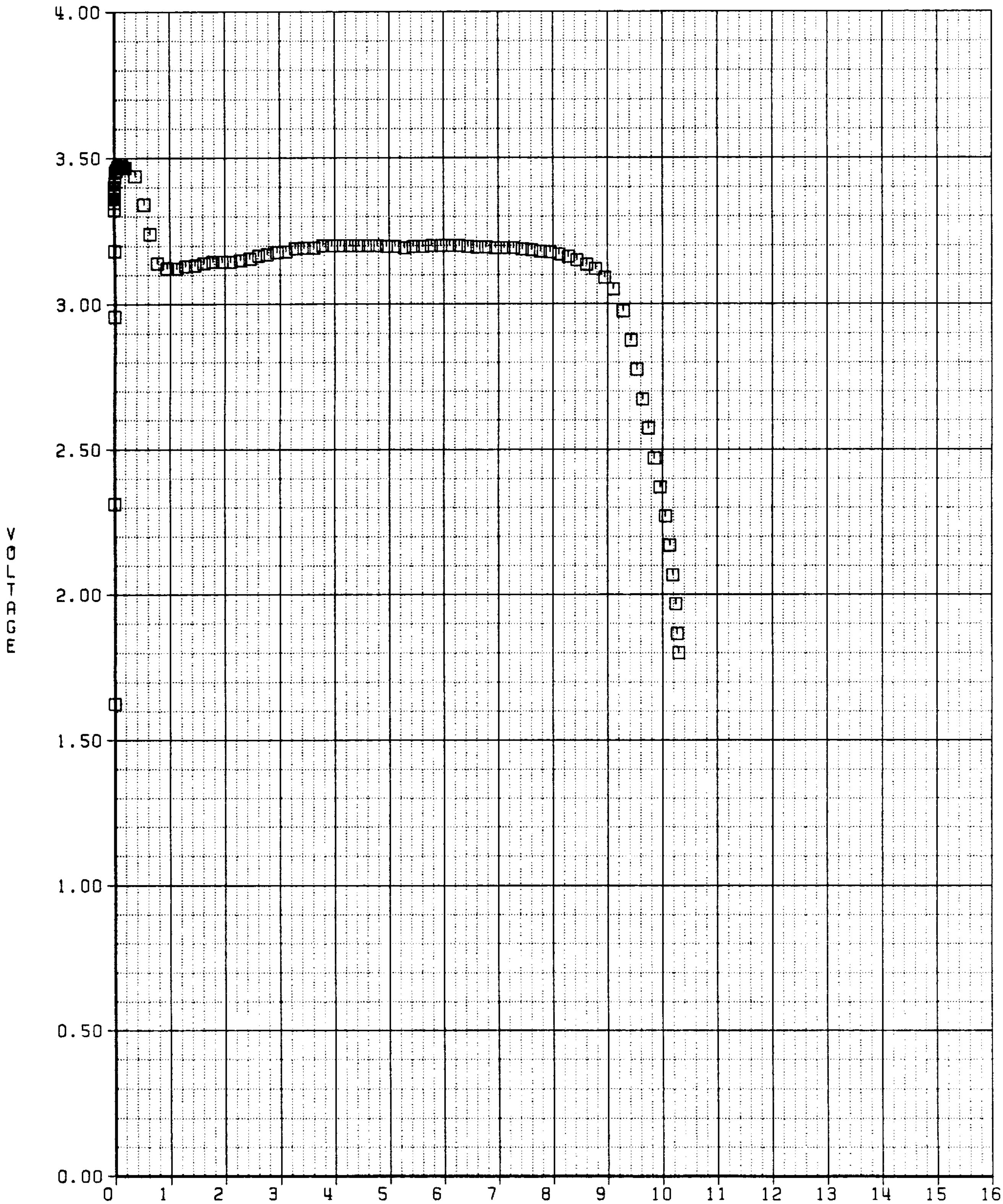
DAY 054 TUE. FEB 23 1993 12:03:04 PM

Figure 126

NASA 1.8M LGC BCX D CELL
1 YR STORAGE AT RM TEMP/1 AMP DISCHARGE AT RT

MACCOR3 ID 1258 OF NASA D CELL STUDY

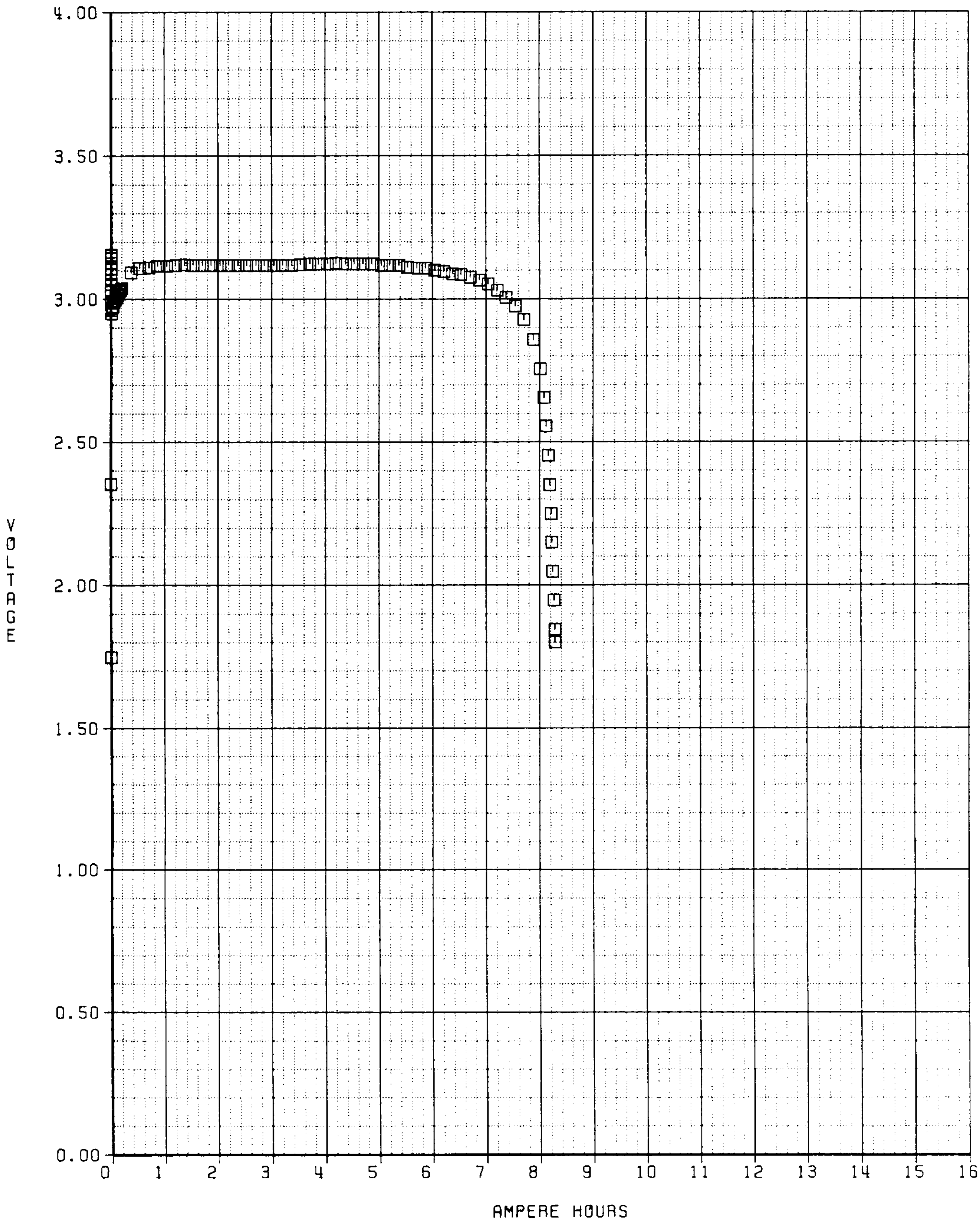


GPLOT(REV. 3.5) DAY 054 TUE, FEB 23 1993 12:57:34 PM

Figure 127

NASA 0.6M LGC TC D CELL
1 YR STORAGE AT RM TEMP/1 AMP DISCHARGE AT RT

MACCOR3 ID 1259 OF NASA D CELL STUDY



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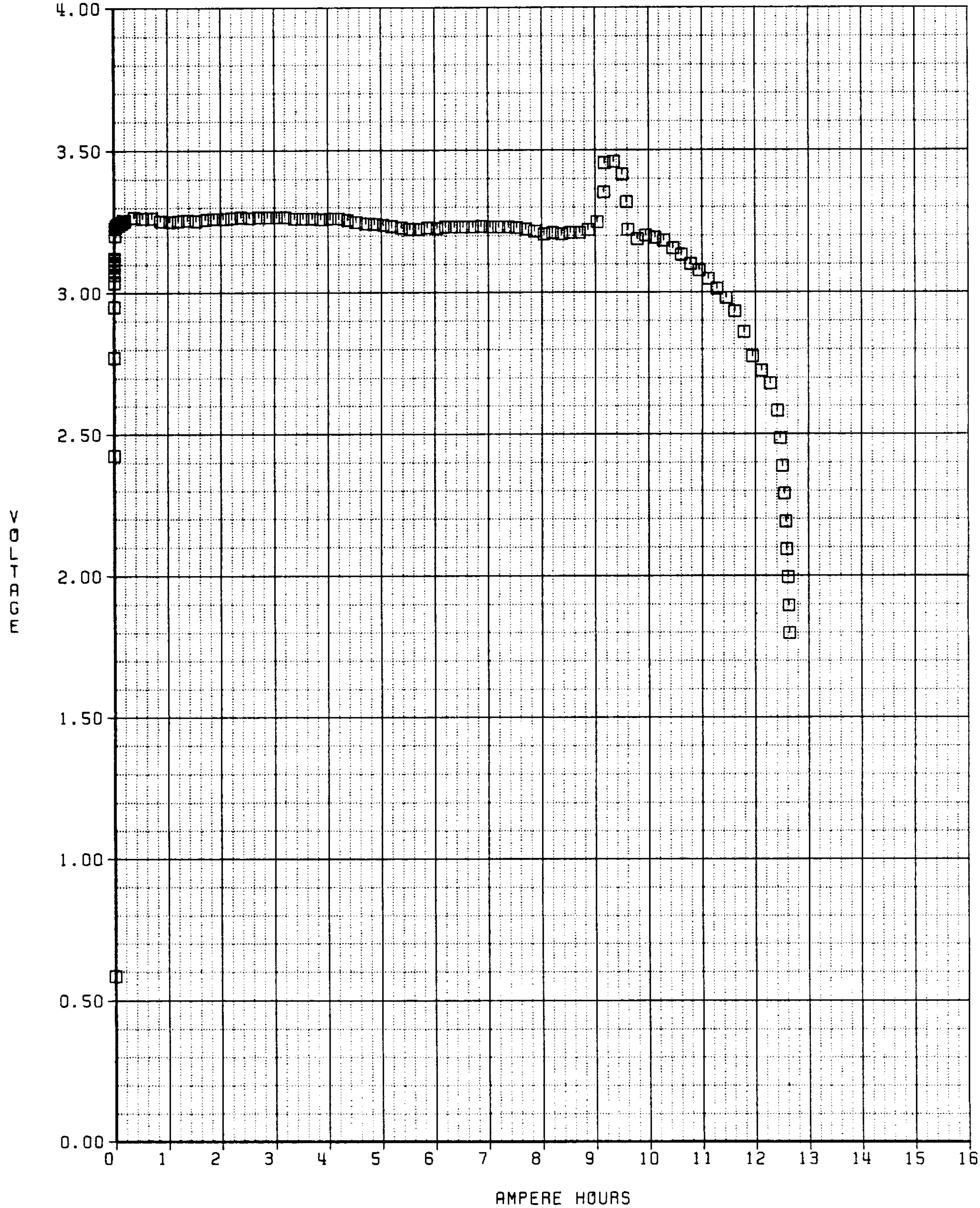
DAY 054 TUE. FEB 23 1993 1:01:16 PM

Figure 128

NASA 1.2M LGC CSC D CELL
1 YR STORAGE AT RM TEMP/1 AMP DISCHARGE AT RT

MACCOR3 ID 1262 OF NASA D CELL STUDY



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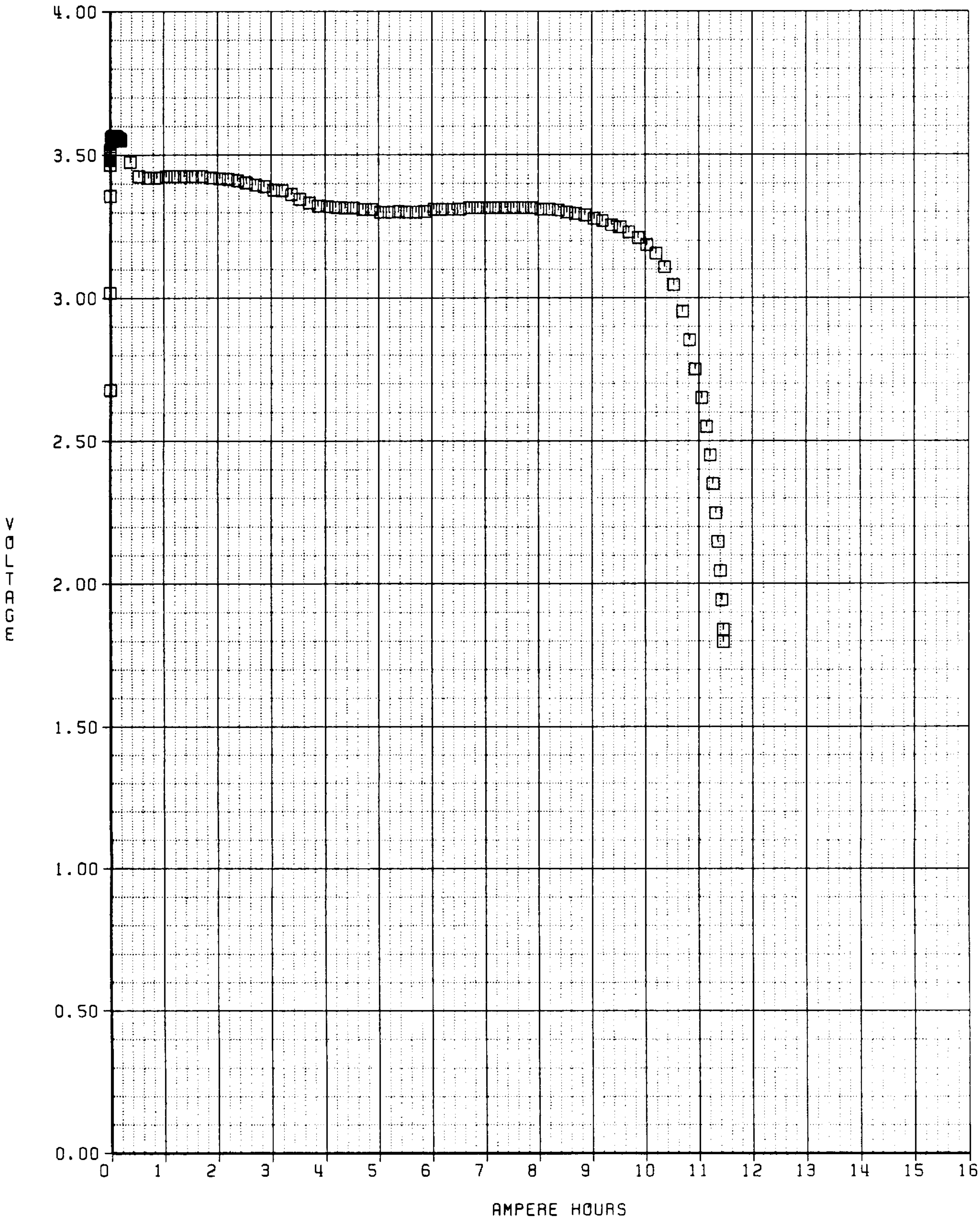
DAY 054 TUE. FEB 23 1993 2:13:19 PM

Figure 129

UNIV 1.2M LGC BCX D CELL
1 YR STORAGE AT RM TEMP/1 AMP DISCHARGE AT RT

MACCOR3 ID 1265 OF NASA D CELL STUDY

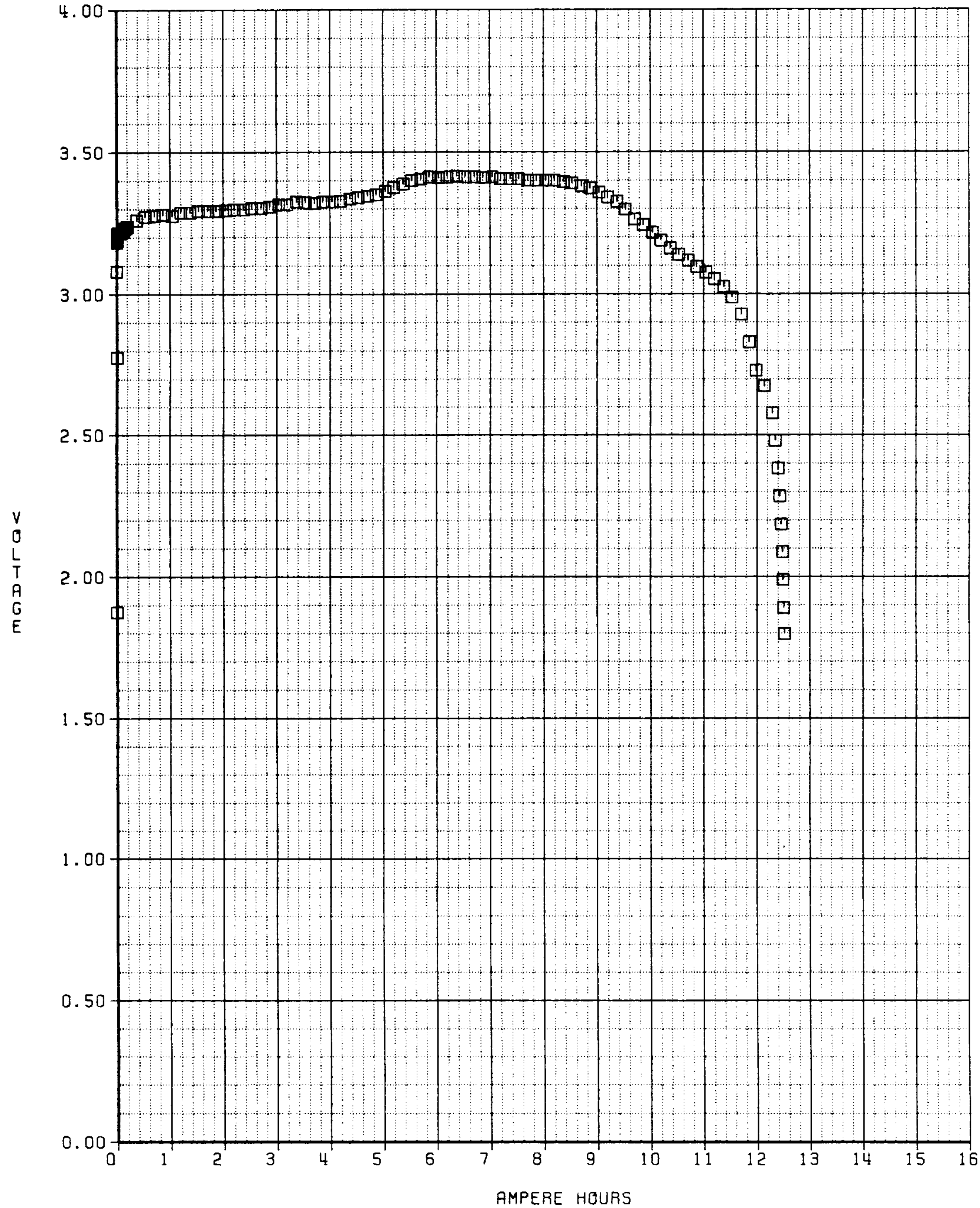


GPLOT (REV. 3.5)   DAY 054 TUE, FEB 23 1993 2:26:29 PM

Figure 130

UNIV 0.6M LGC CSC D CELL
1 YR STORAGE AT RM TEMP/1 AMP DISCHARGE AT RT

MACCOR3 ID 1272 OF NASA D CELL STUDY



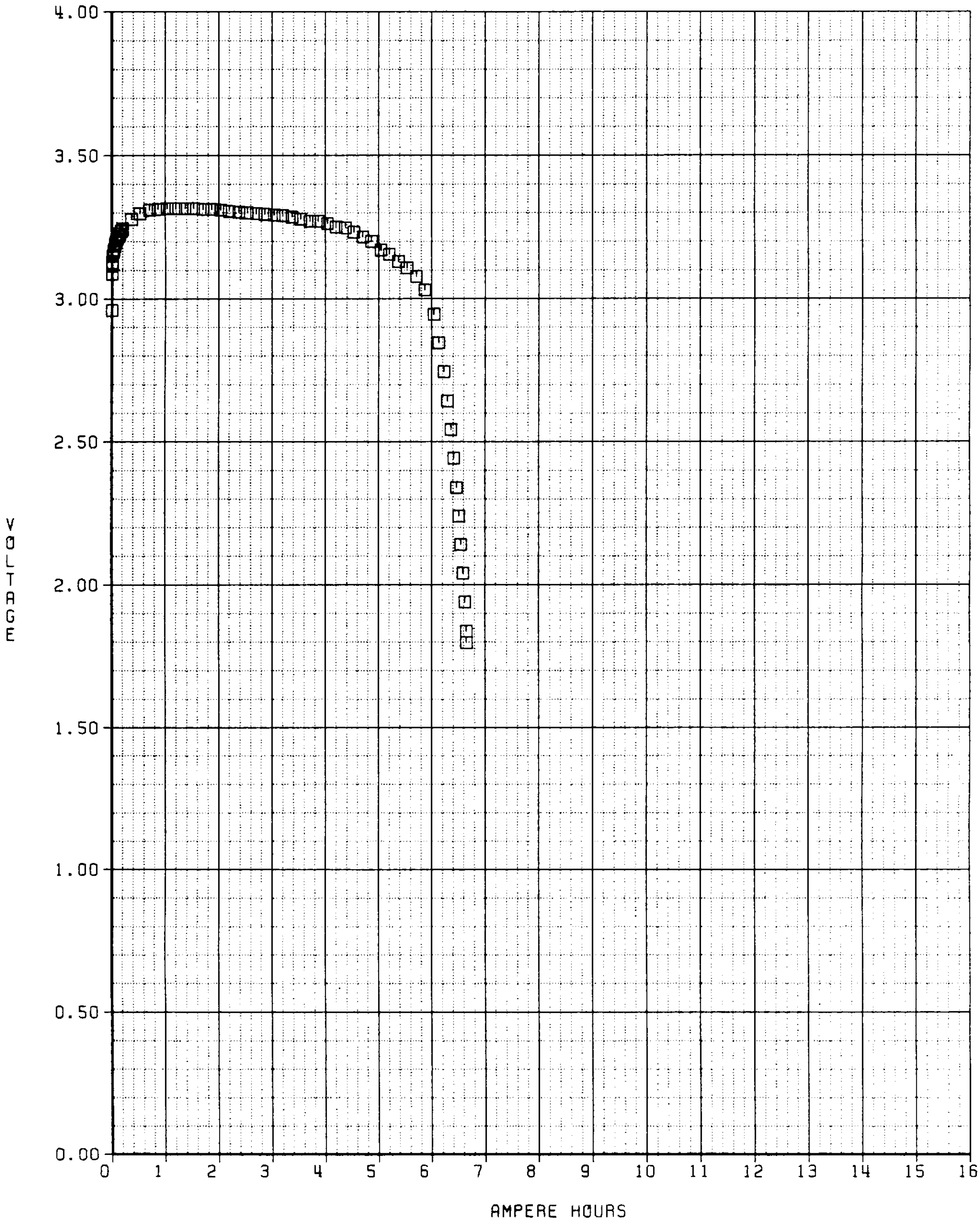
GPLOT(REV. 3.5)

DAY 054 TUE, FEB 23 1993 2:50:07 PM

Figure 131

JPL 1.8M LGC BCX D CELL
1 YR STORAGE AT RM TEMP/1 AMP DISCHARGE AT RT

MACCOR3 ID 1275 OF NASA D CELL STUDY



GPLOT(REV. 3.5) DAY 054 TUE, FEB 23 1993 2:55:35 PM

Figure 132

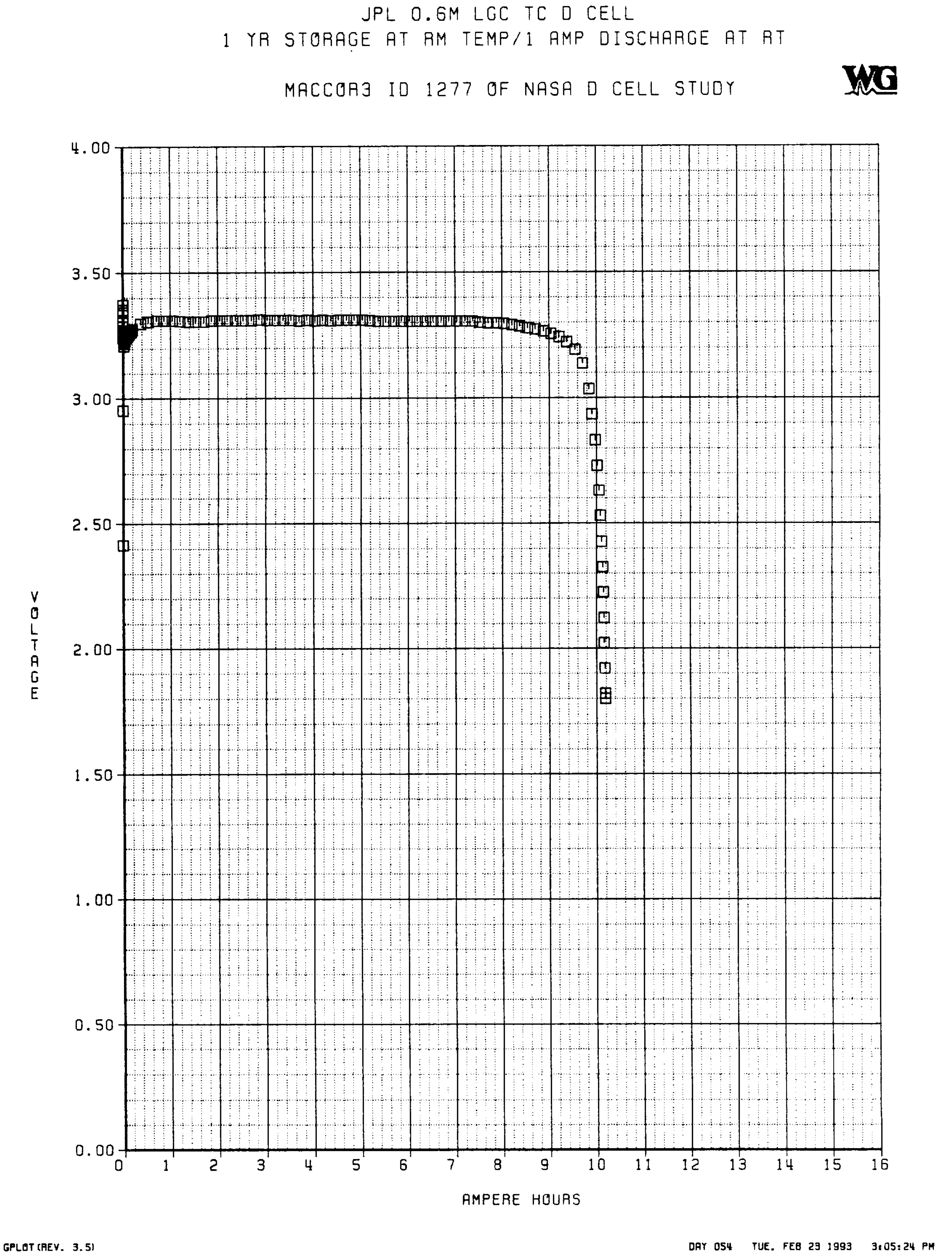

JPL 0.6M LGC TC D CELL
1 YR STORAGE AT RM TEMP/1 AMP DISCHARGE AT RT
MACCOR3 ID 1277 OF NASA D CELL STUDY
WG
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
VOLTAGE
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
AMPERE HOURS
GPLOT(REV. 3.5)
DAY 054 TUE. FEB 23 1993 3:05:24 PM

Figure 133

JPL 1.2M LGC CSC D CELL
1 YR STORAGE AT RM TEMP/1 AMP DISCHARGE AT RT

MACCOR3 ID 1282 OF NASA D CELL STUDY

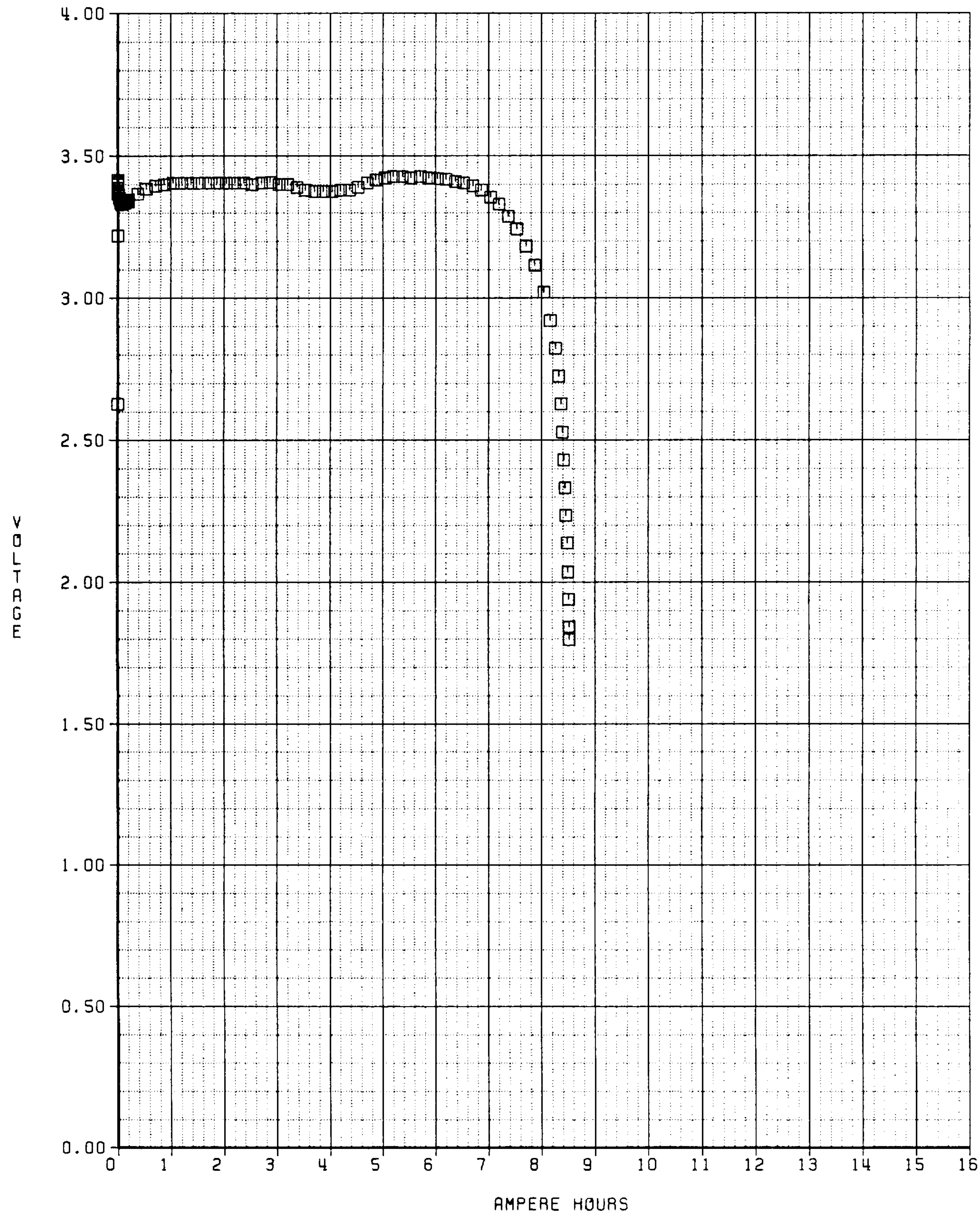


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Figure 134

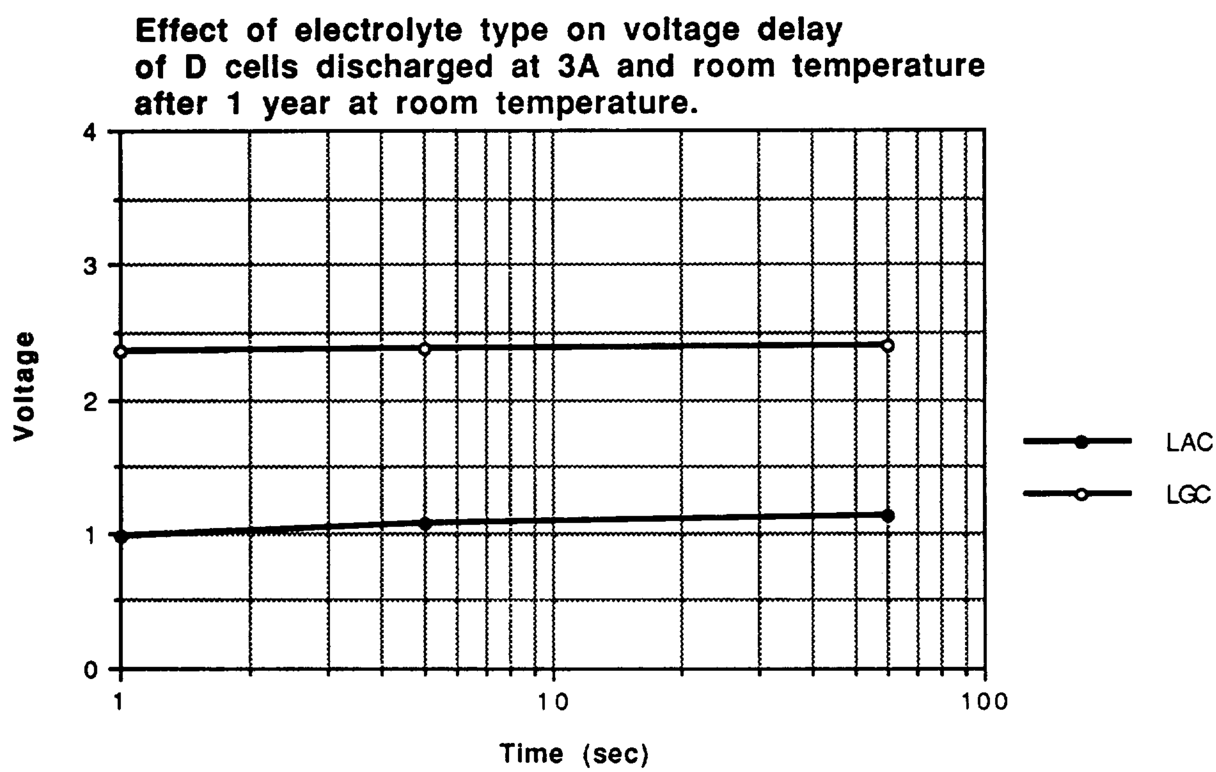

Effect of electrolyte type on voltage delay
of D cells discharged at 3A and room temperature
after 1 year at room temperature.
Voltage
4
3
2
1
0
1
10
100
Time (sec)
LAC
LGC

Figure 135

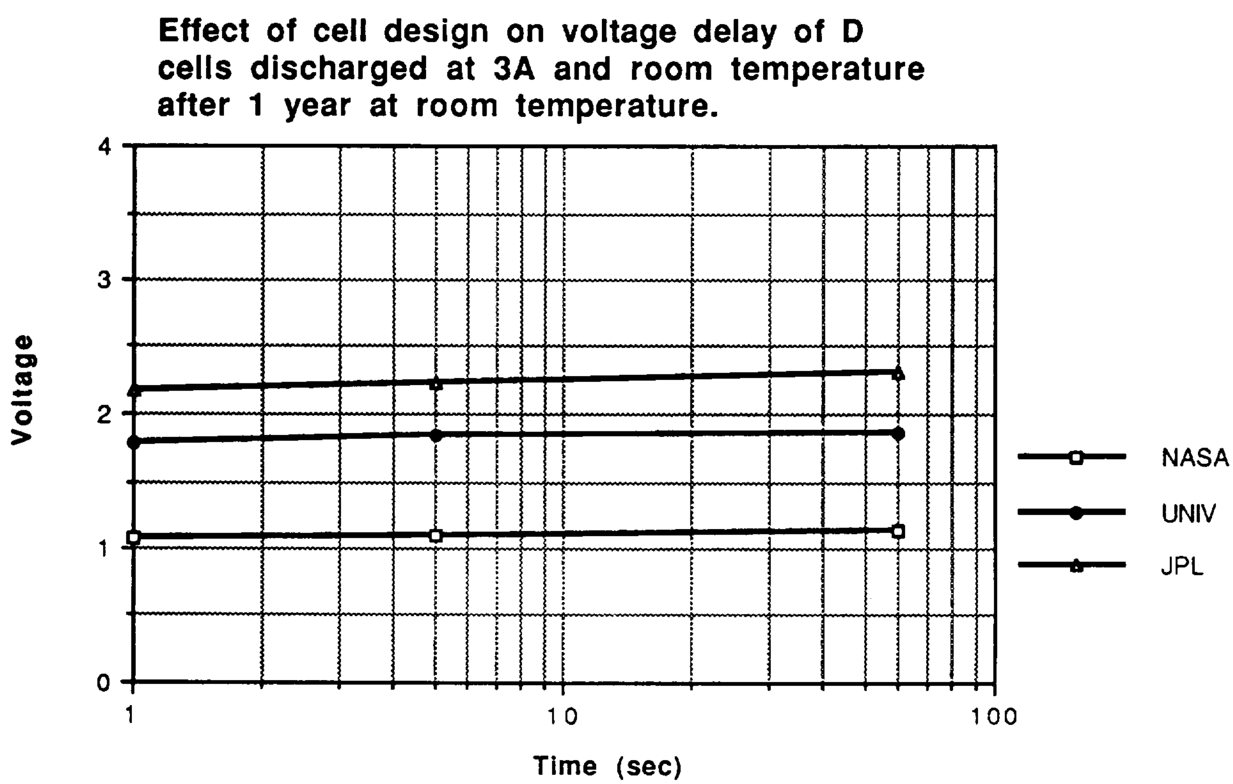

Effect of cell design on voltage delay of D cells discharged at 3A and room temperature after 1 year at room temperature.
Voltage
0
1
2
3
4
1
10
100
Time (sec)
NASA
UNIV
JPL

Figure 136

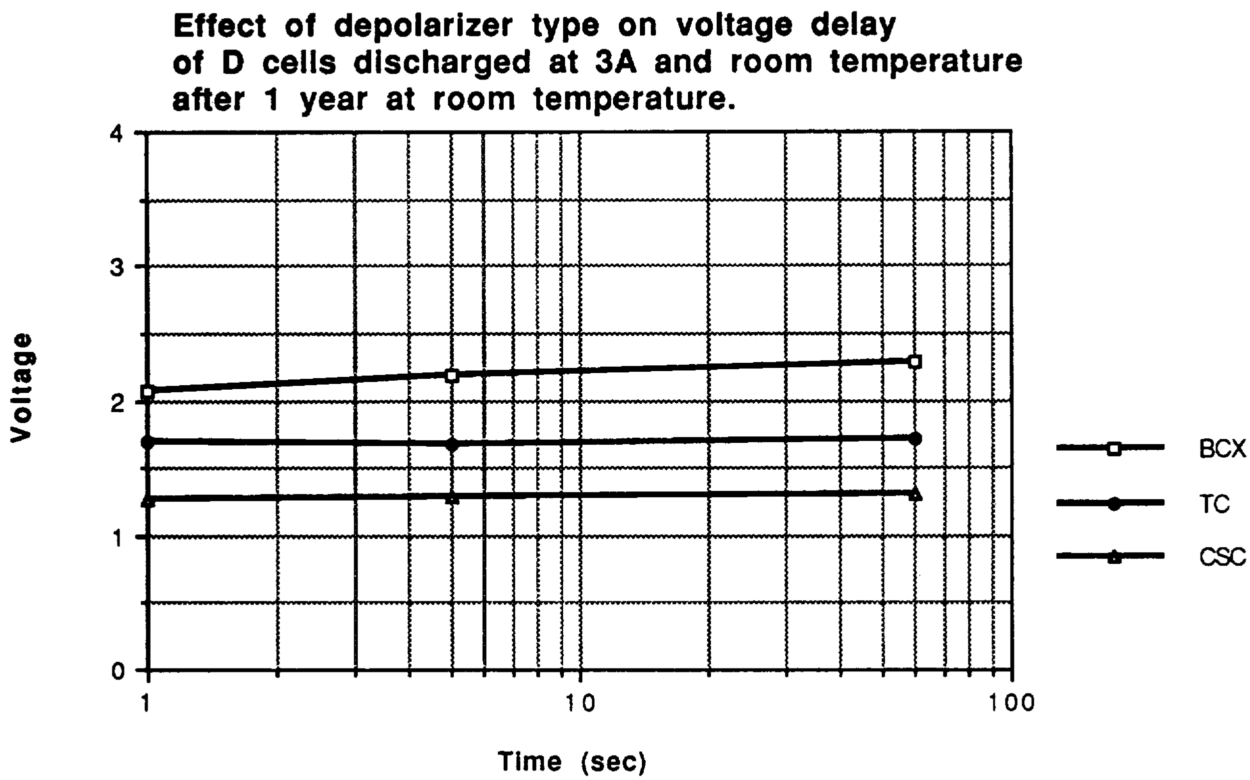

Effect of depolarizer type on voltage delay
of D cells discharged at 3A and room temperature
after 1 year at room temperature.
Voltage
4
3
2
1
0
1
10
100
Time (sec)
BCX
TC
CSC

Figure 137

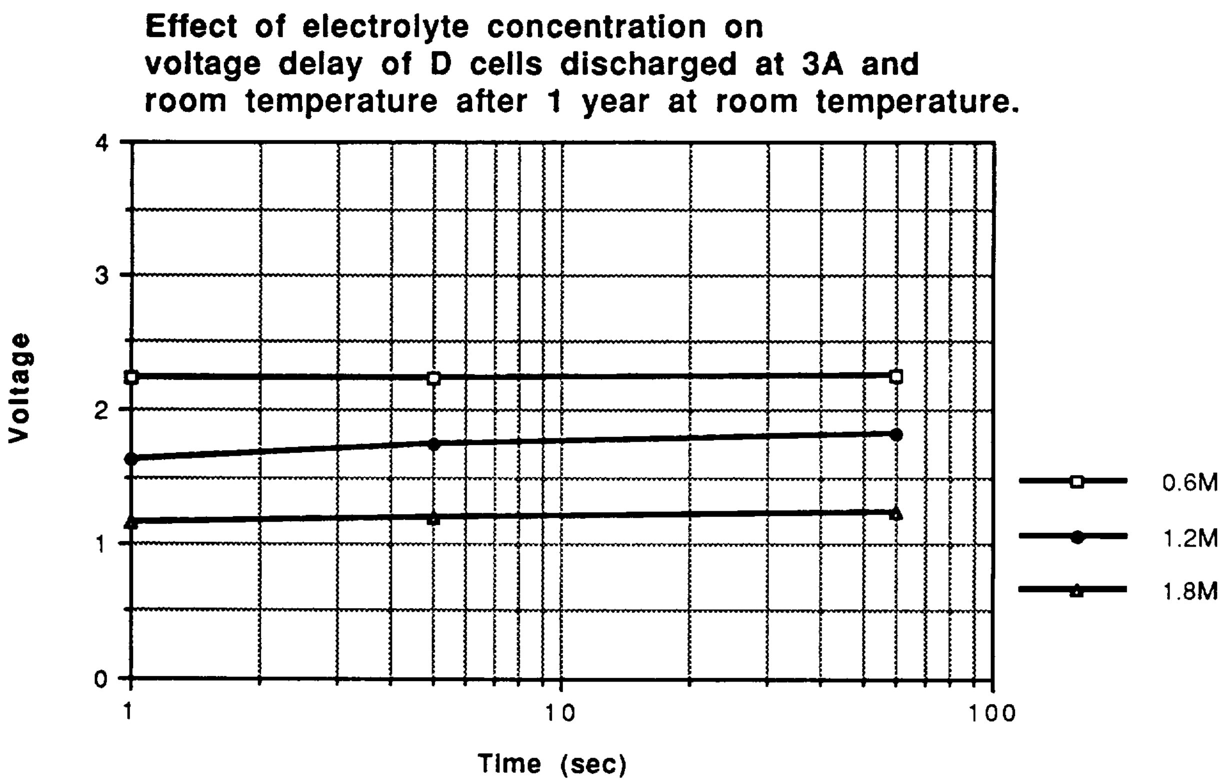

Effect of electrolyte concentration on
voltage delay of D cells discharged at 3A and
room temperature after 1 year at room temperature.
Voltage
4
3
2
1
0
1
10
100
Time (sec)
0.6M
1.2M
1.8M

Figure 138

Effect of electrolyte type on running voltage of D cells discharged at 3A and room temperature after 1 year at room temperature.

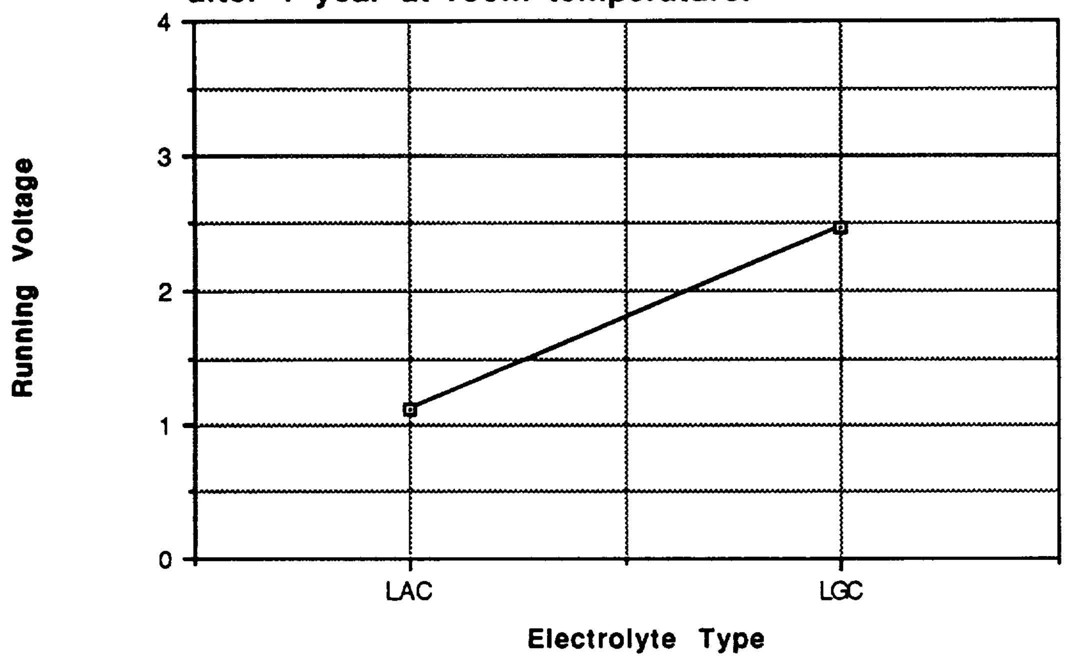


Figure 139

Effect of cell design on running voltage of D cells discharged at 3A and room temperature after 1 year at room temperature.

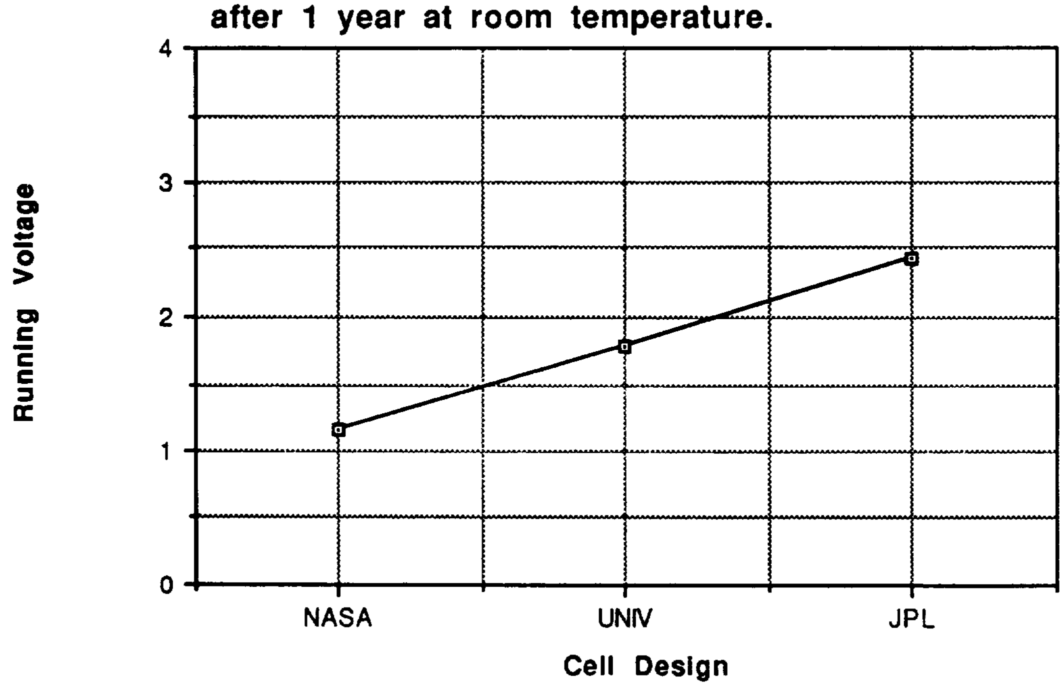


Figure 140

Effect of depolarizer type on running voltage of D cells discharged at 3A and room temperature after 1 year at room temperature.

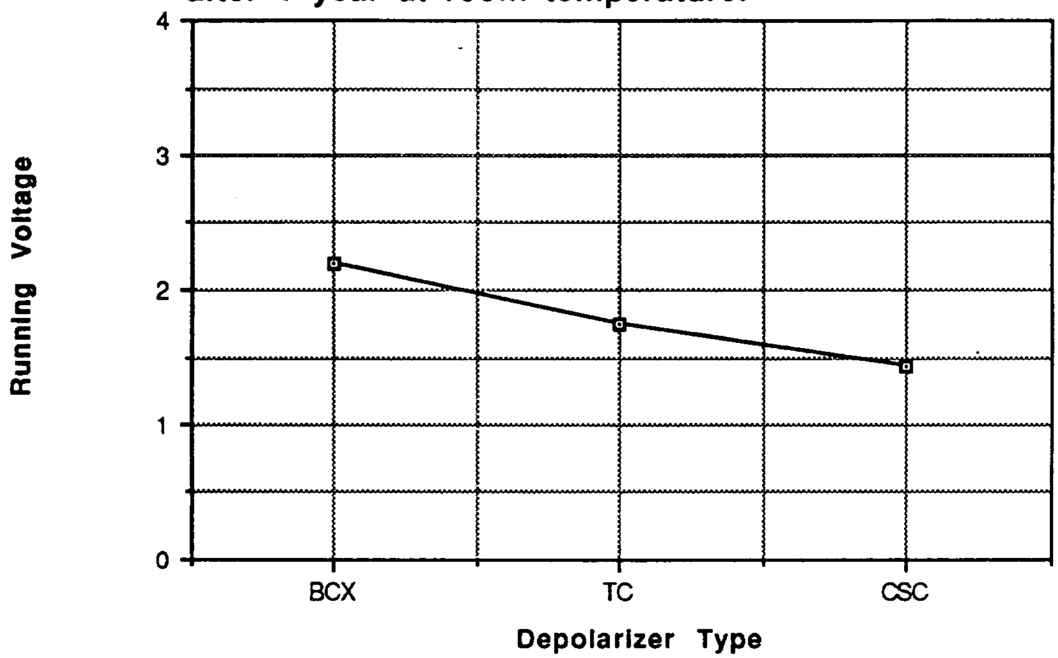
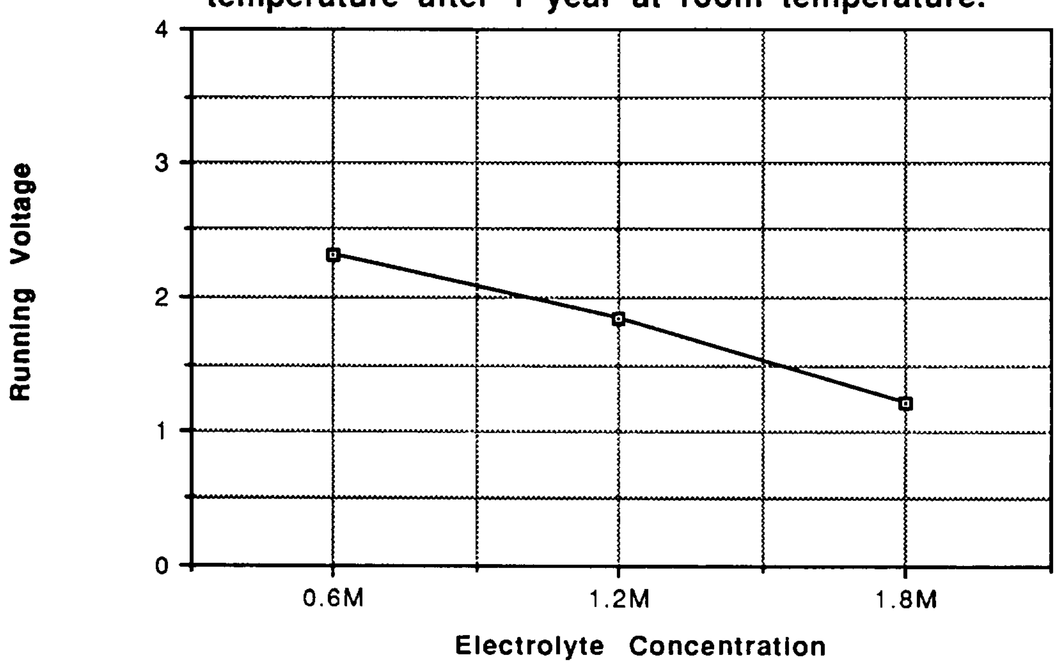


Figure 141

Effect of electrolyte concentration on running voltage of D cells discharged at 3A and room temperature after 1 year at room temperature.



for 19% of the variation in discharge capacity. Figures 142 & 143 illustrate the effect of the electrolyte type and the cell design on capacity, respectively. The depolarizer and the electrolyte concentration had no effect on capacity under this set of conditions.

The factor affecting the capacity retention of D cells was the electrolyte type, which contributed 25.8% to the variation in performance. The remaining variation was due mainly to outside factors. Cells with LGC electrolyte retained and average of 74.5% of their initial capacity, compared to 30% capacity retention in cells with LAC. Refer to figure 144 for a comparison of the two electrolytes.

The discharge curves for this portion of the performance testing are included in figures 145 - 156. Six of the eighteen configurations failed to operate under these conditions, therefore there are no discharge curves for those groups. Appendix G contains the ANOVA reports for the five performance attributes analyzed for this portion of the testing.

SUMMARY OF DISCHARGE DATA

Under the majority of test conditions, the factor which affected performance the most was the electrolyte type, and the LGC electrolyte outperformed the LAC electrolyte in every case. The LGC electrolyte is effective in alleviating voltage delay while at the same time improving delivered capacity and capacity retention.

The depolarizer type is the second most common factor having an effect on electrical performance of Li/oxyhalide cells. Under all test conditions, cells with BCX depolarizer had better start up characteristics than cells with either CSC or TC depolarizers. The depolarizer also affected running voltages under some conditions. While the running voltage was the most difficult performance attribute to analyze,especially at low temperature, the BCX depolarizer produced the highest running voltages in cells discharged under 1A and room temperature. However, at the higher rate discharge condition, cells with CSC depolarizer had higher running voltages. The depolarizer type affected capacity of fresh cells discharged at 1A and 3A room temperature, and had a slight effect on fresh 3A discharge at -25°C. CSC depolarizer offers the highest fresh capacities of the three depolarizers studied.

The cell design plays a limited role in electrical performance of Li/oxyhalide cells. The JPL design is favored over the other two designs for providing higher running voltages in fresh cells discharged at 1A and room temperature, larger high rate capacity of fresh cells, and higher running voltages in aged cells discharged at high rate.

Figure 142

Effect of electrolyte type on capacity of D cells discharged at 3A and room temperature after 1 year at room temperature.

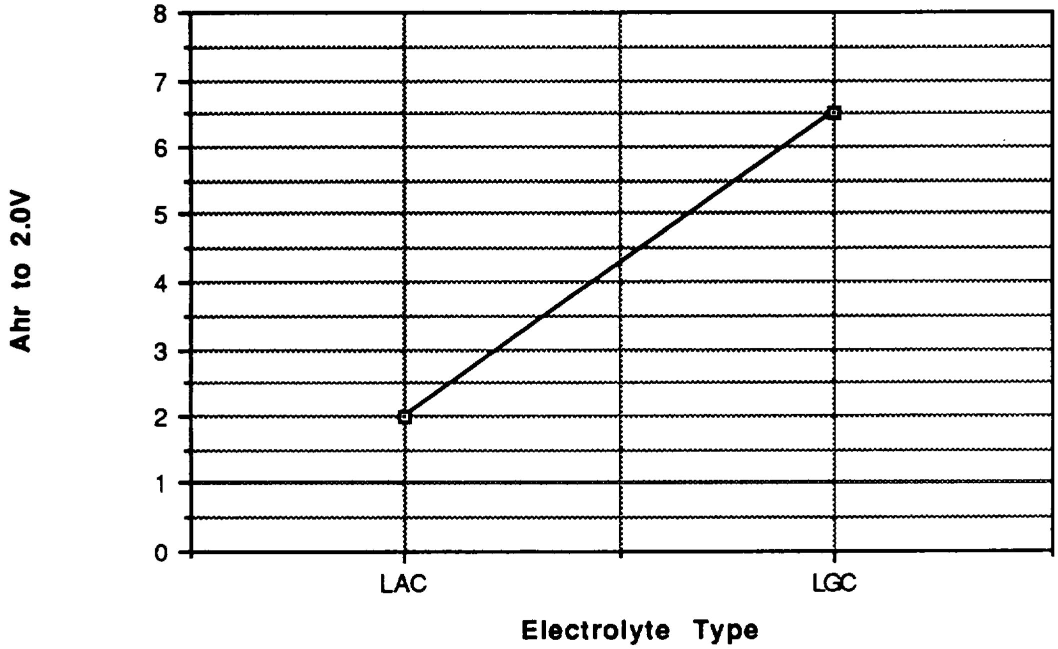


Figure 143

Effect of cell design on capacity of D cells discharged at 3A and room temperature after 1 year at room temperature.

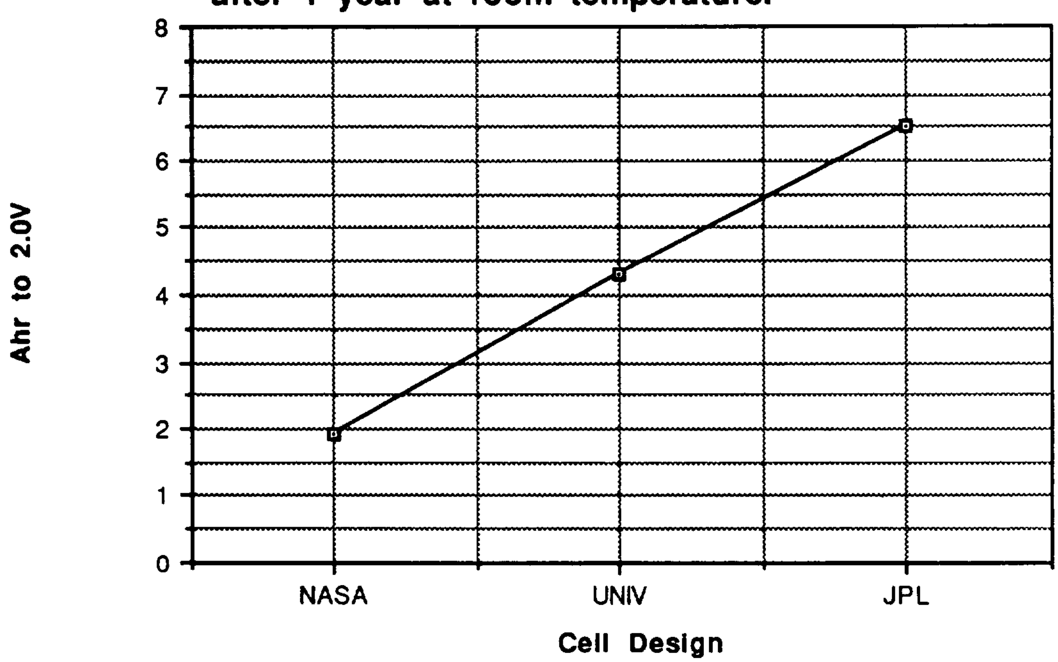


Figure 144

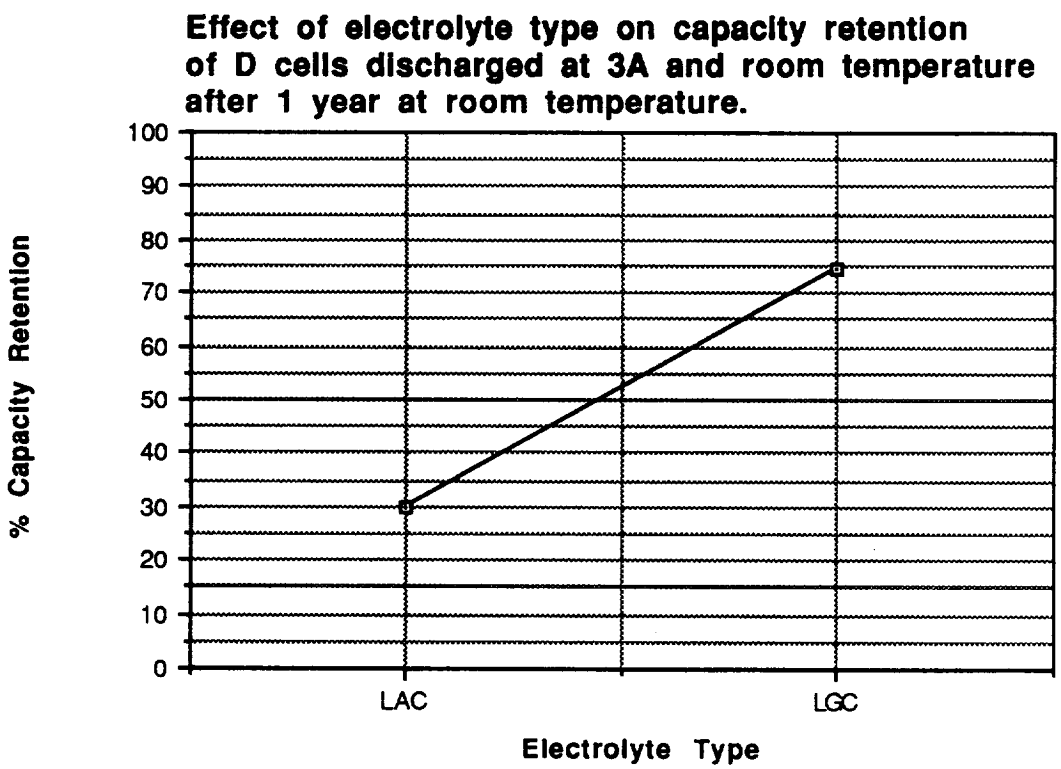
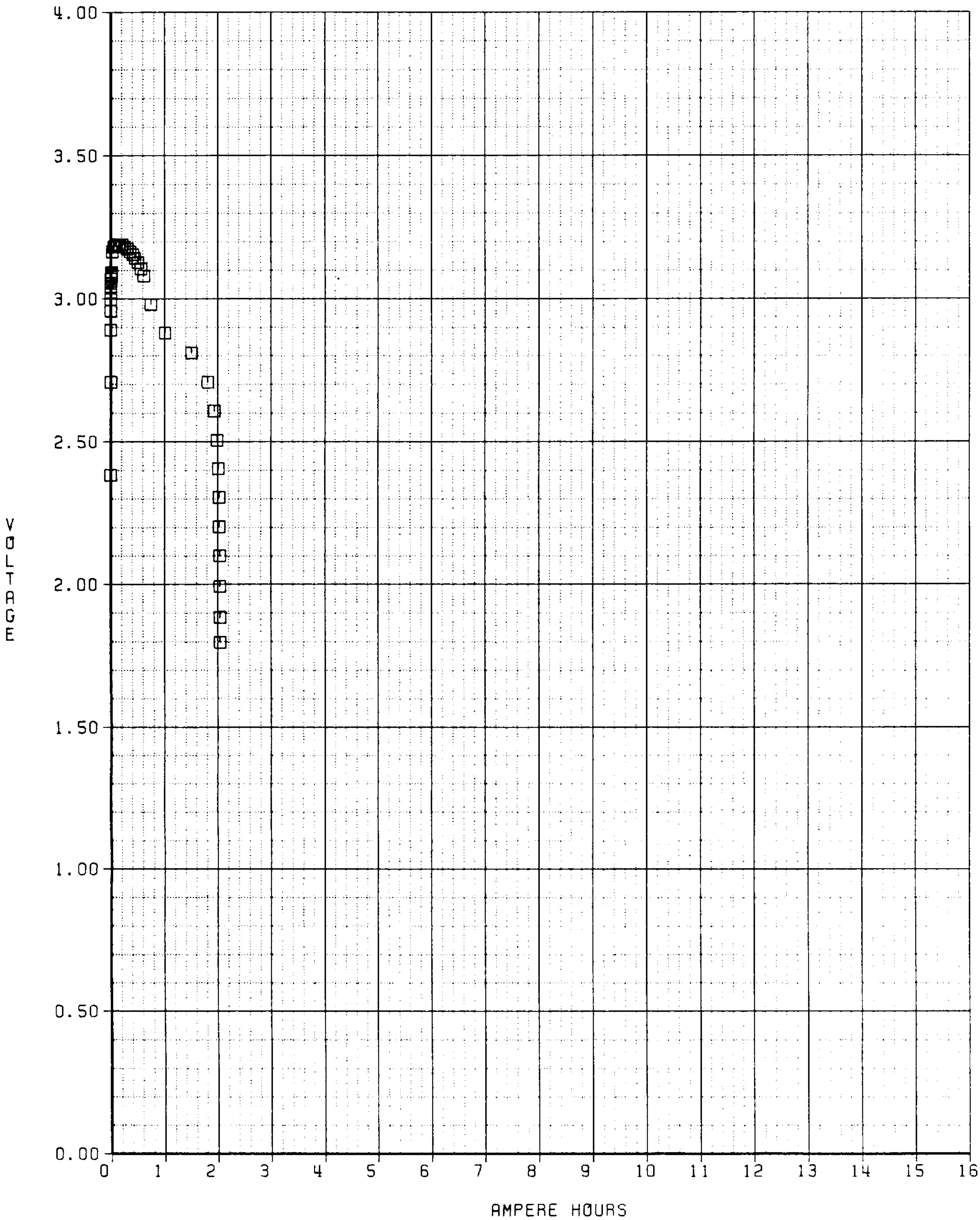

Effect of electrolyte type on capacity retention
of D cells discharged at 3A and room temperature
after 1 year at room temperature.
% Capacity Retention
100
90
80
70
60
50
40
30
20
10
0
LAC
LGC
Electrolyte Type

Figure 145

NASA 0.6M LAC BCX D CELL
1 YR STORAGE AT RM TEMP/3 AMP DISCHARGE AT RT

MACCOR3 ID 1175 OF NASA D CELL STUDY



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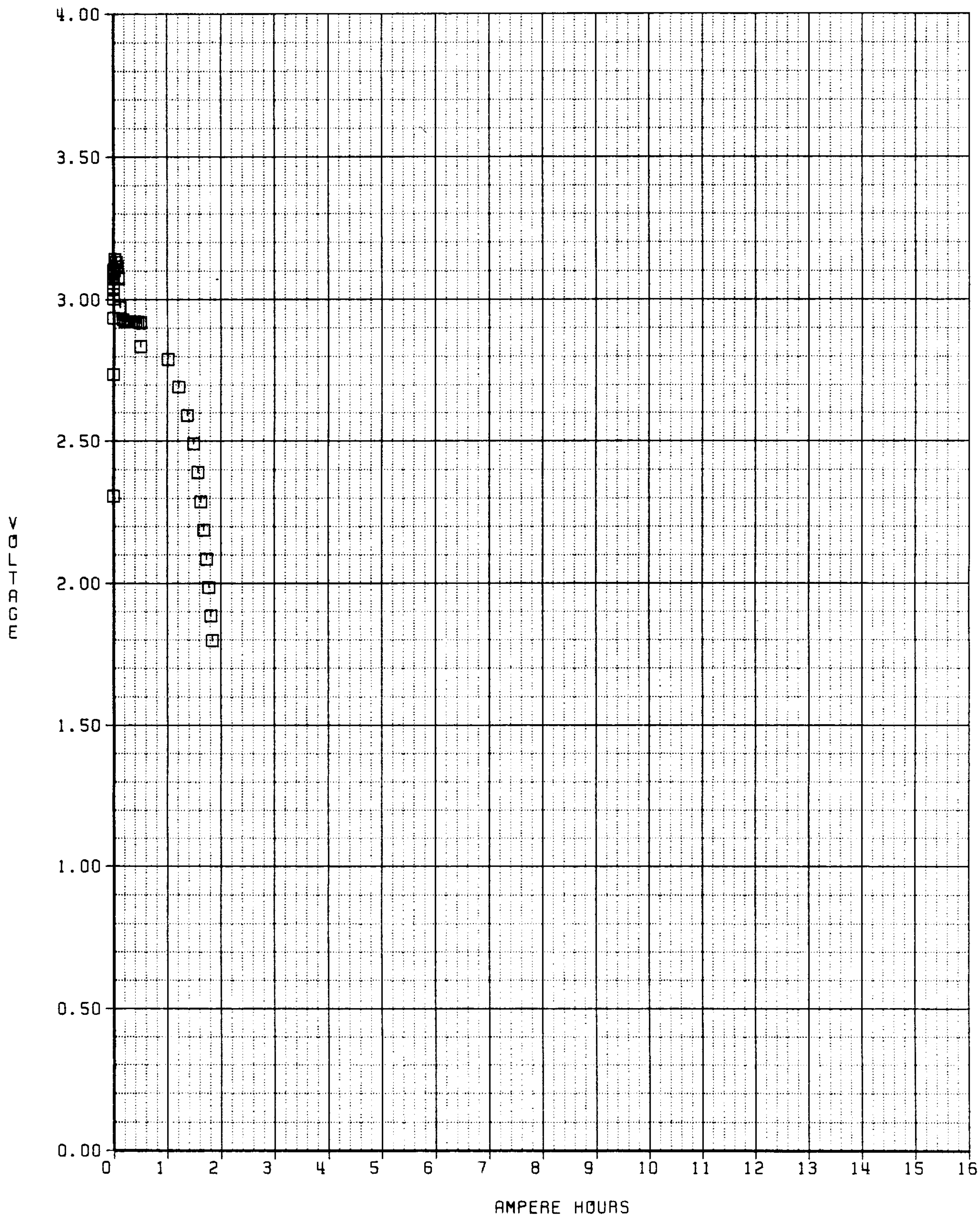
DAY 044 SAT. FEB 13 1993 11:44:13 AM

Figure 146

UNIV 0.6M LAC BCX D CELL
1 YR STORAGE AT AM TEMP/3 AMP DISCHARGE AT RT

MACCOR3 ID 1185 OF NASA D CELL STUDY



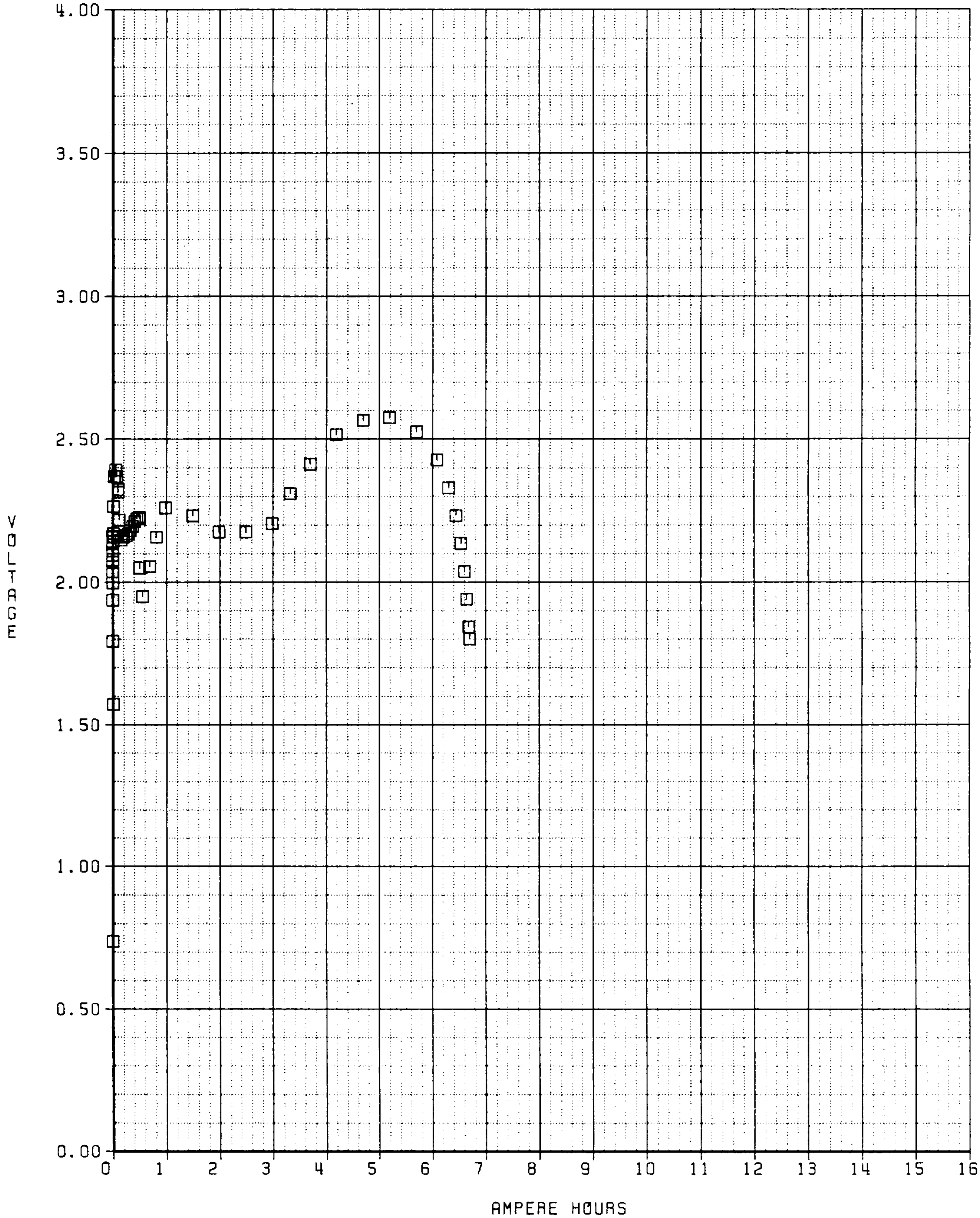
GPLOT (REV. 3.5)

DAY 054 TUE. FEB 23 1993 11:43:02 AM

Figure 147

JPL 1.2M LAC BCX D CELL
1 YR STORAGE AT RM TEMP/3 AMP DISCHARGE AT RT

MACCOR3 ID 1193 OF NASA D CELL STUDY



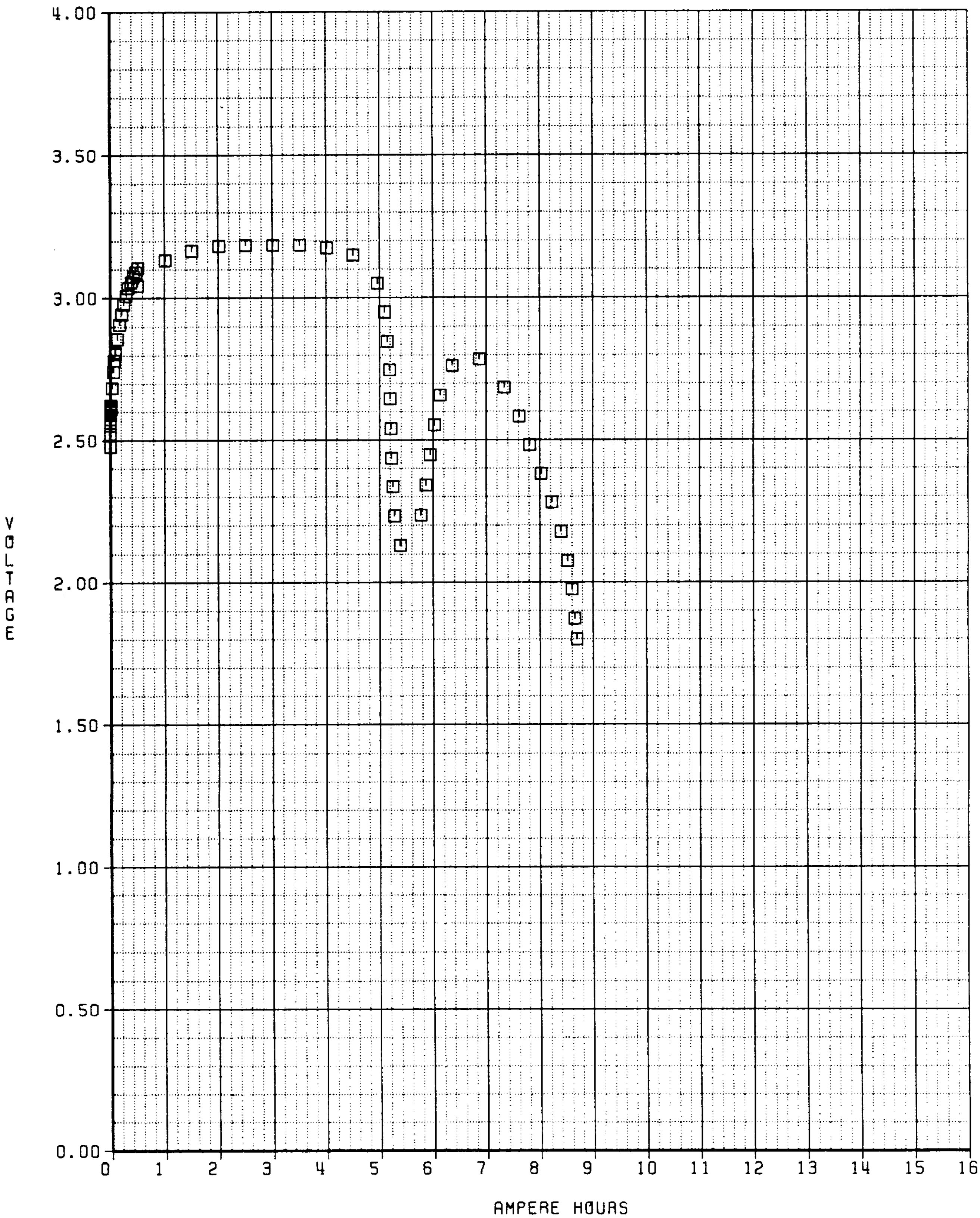
GPLOT(REV. 3.5)

DAY 054 TUE, FEB 23 1993 11:47:16 AM

Figure 148

JPL 1.8M LAC TC D CELL
1 YR STORAGE AT RM TEMP/3 AMP DISCHARGE AT RT

MACCOR3 ID 1196 OF NASA D CELL STUDY



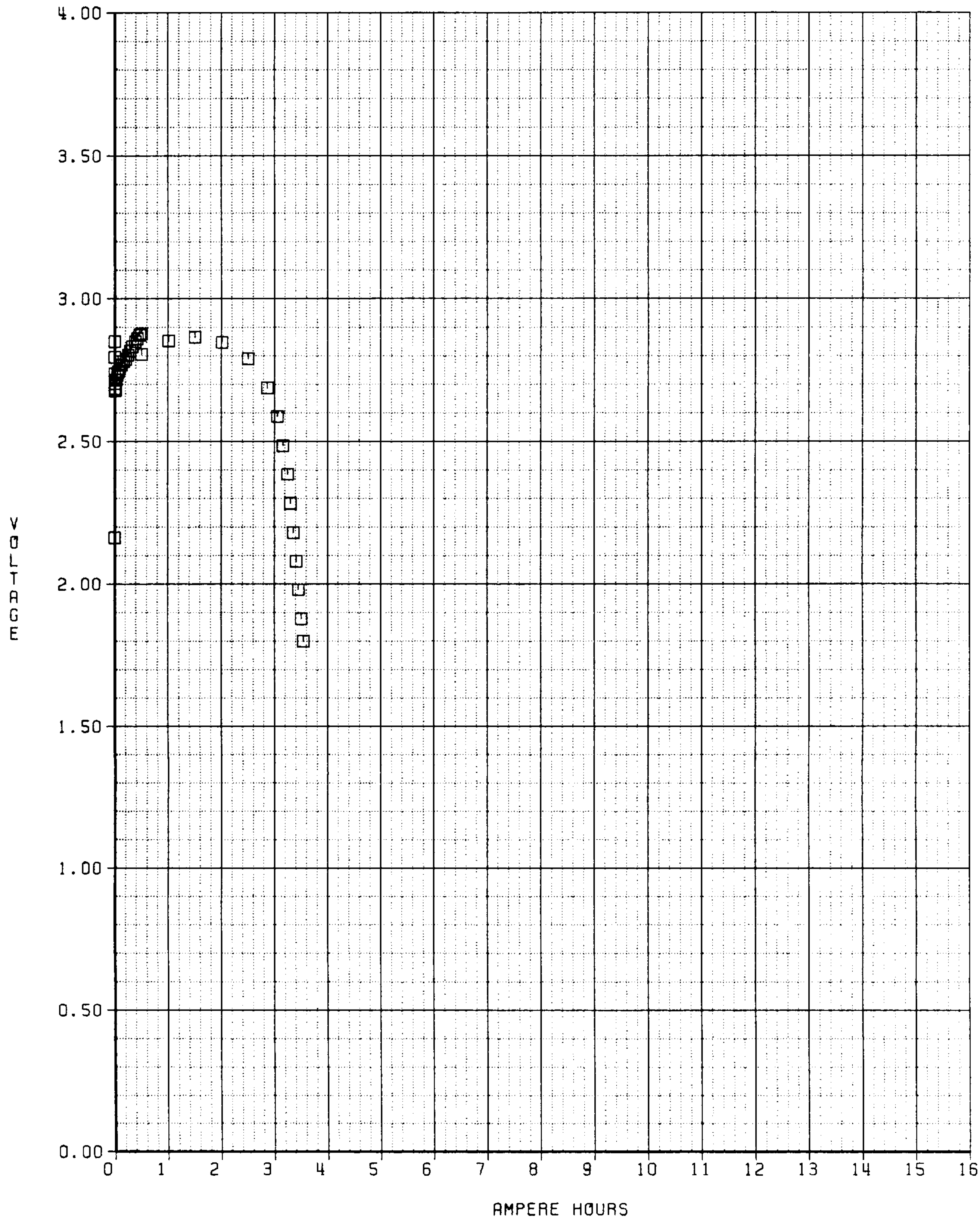
GPLOT(REV. 3.5)

DAT 054 TUE, FEB 23 1993 12:45:55 PM

Figure 149

NASA 0.6M LGC TC D CELL
1 YR STORAGE AT RM TEMP/3 AMP DISCHARGE AT RT

MACCOR3 ID 1206 OF NASA D CELL STUDY



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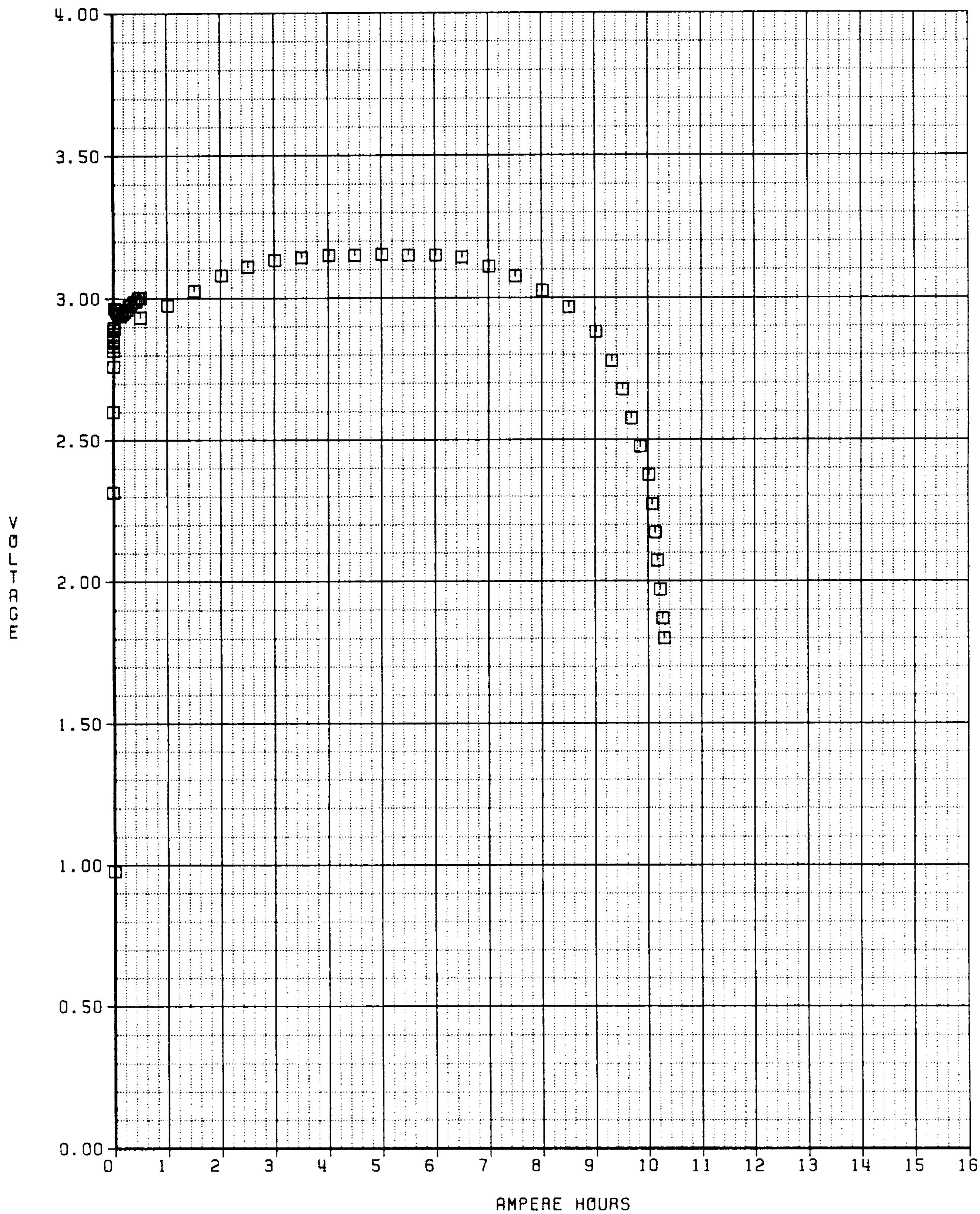
DAY 054 TUE. FEB 23 1993 1:04:07 PM

Figure 150

NASA 1.2M LGC CSC D CELL
1 YR STORAGE AT AM TEMP/3 AMP DISCHARGE AT RT

MACCOR3 ID 1209 OF NASA D CELL STUDY



GPLOT(REV. 3.5)

DAY 054 TUE, FEB 23 1993 2:10:31 PM

Figure 151

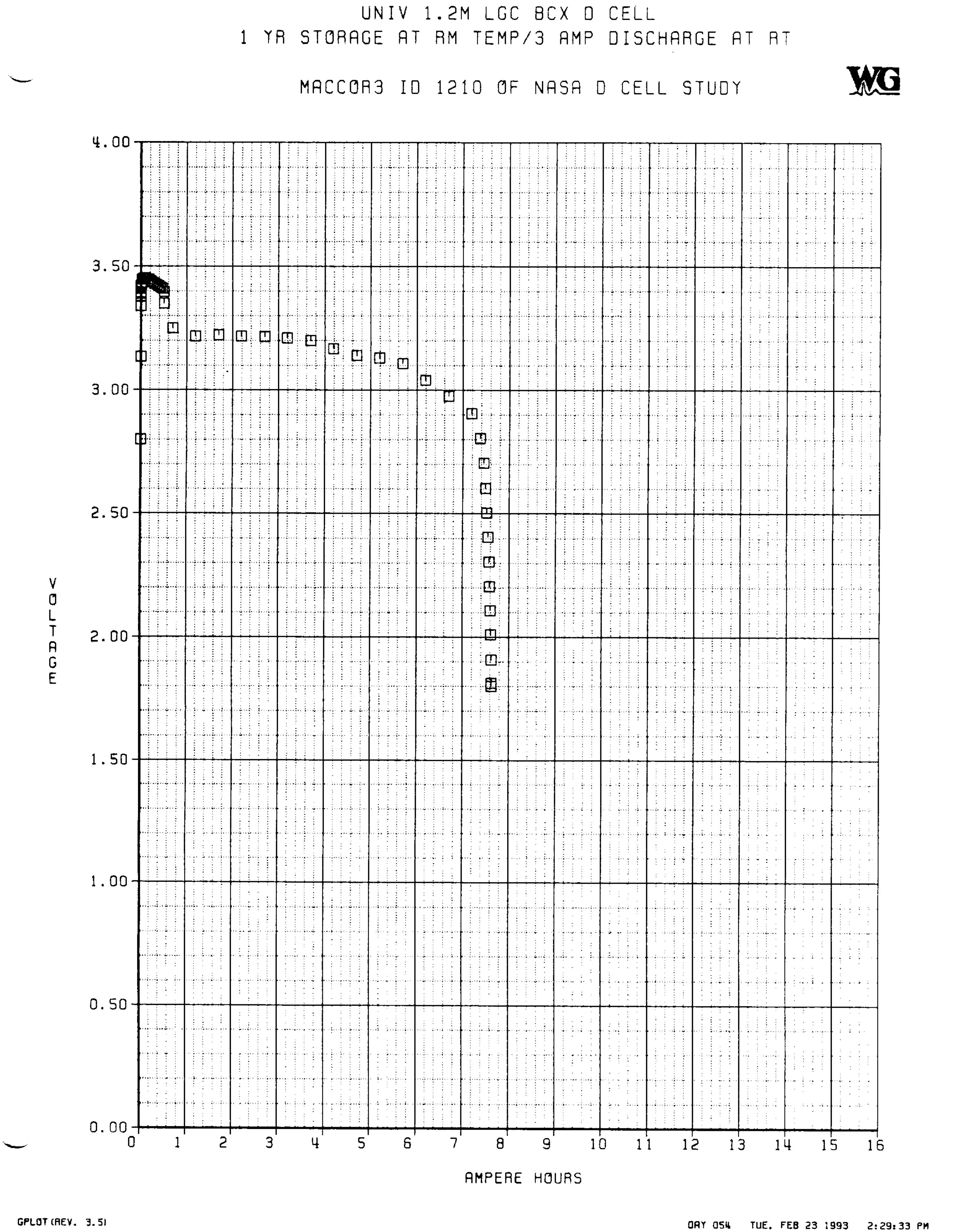

UNIV 1.2M LGC BCX D CELL
1 YR STORAGE AT RM TEMP/3 AMP DISCHARGE AT RT
MACCOR3 ID 1210 OF NASA D CELL STUDY
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
VOLTAGE
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
AMPERE HOURS
GPLOT (REV. 3.5)
DAY 054 TUE. FEB 23 1993 2:29:33 PM

Figure 152

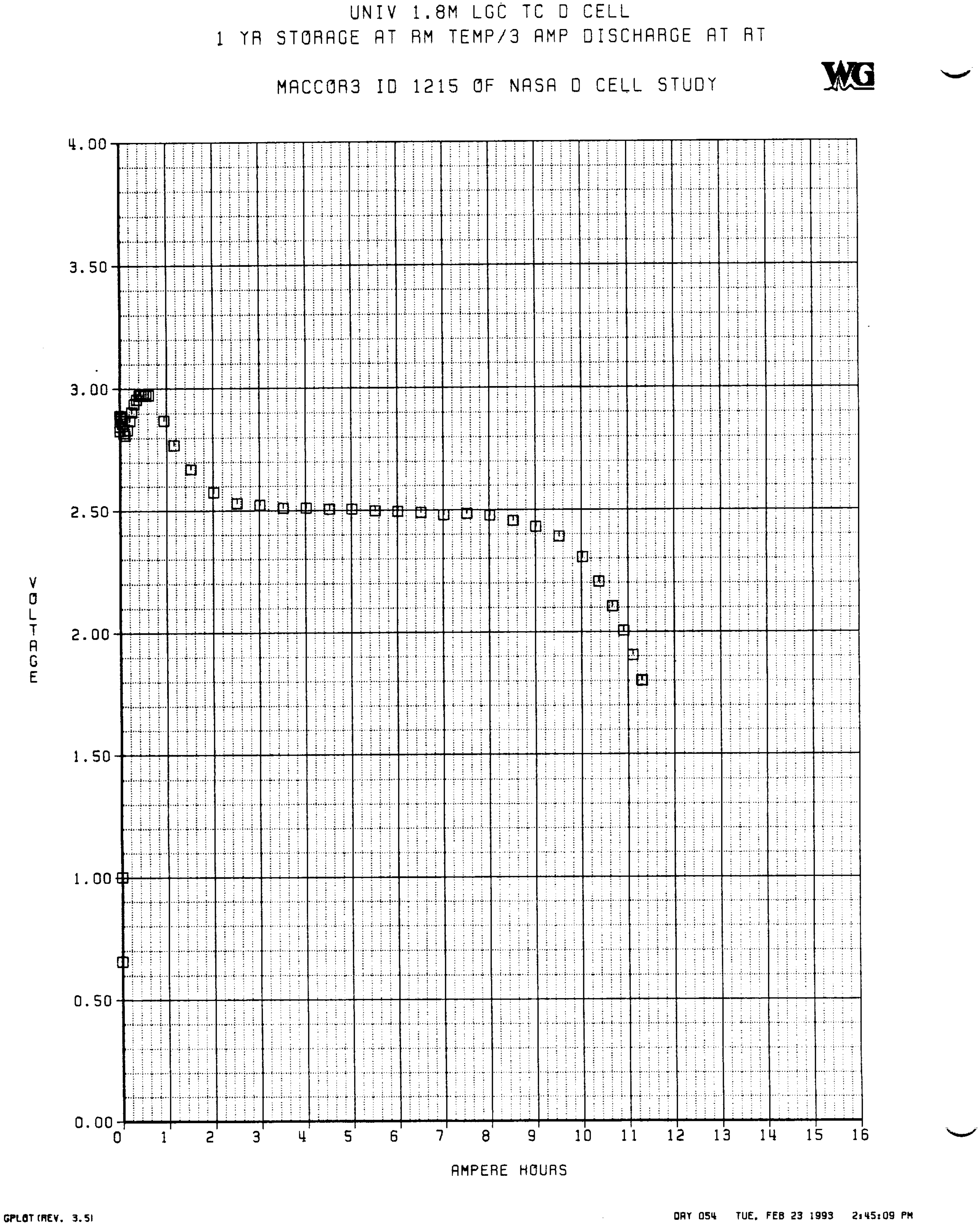
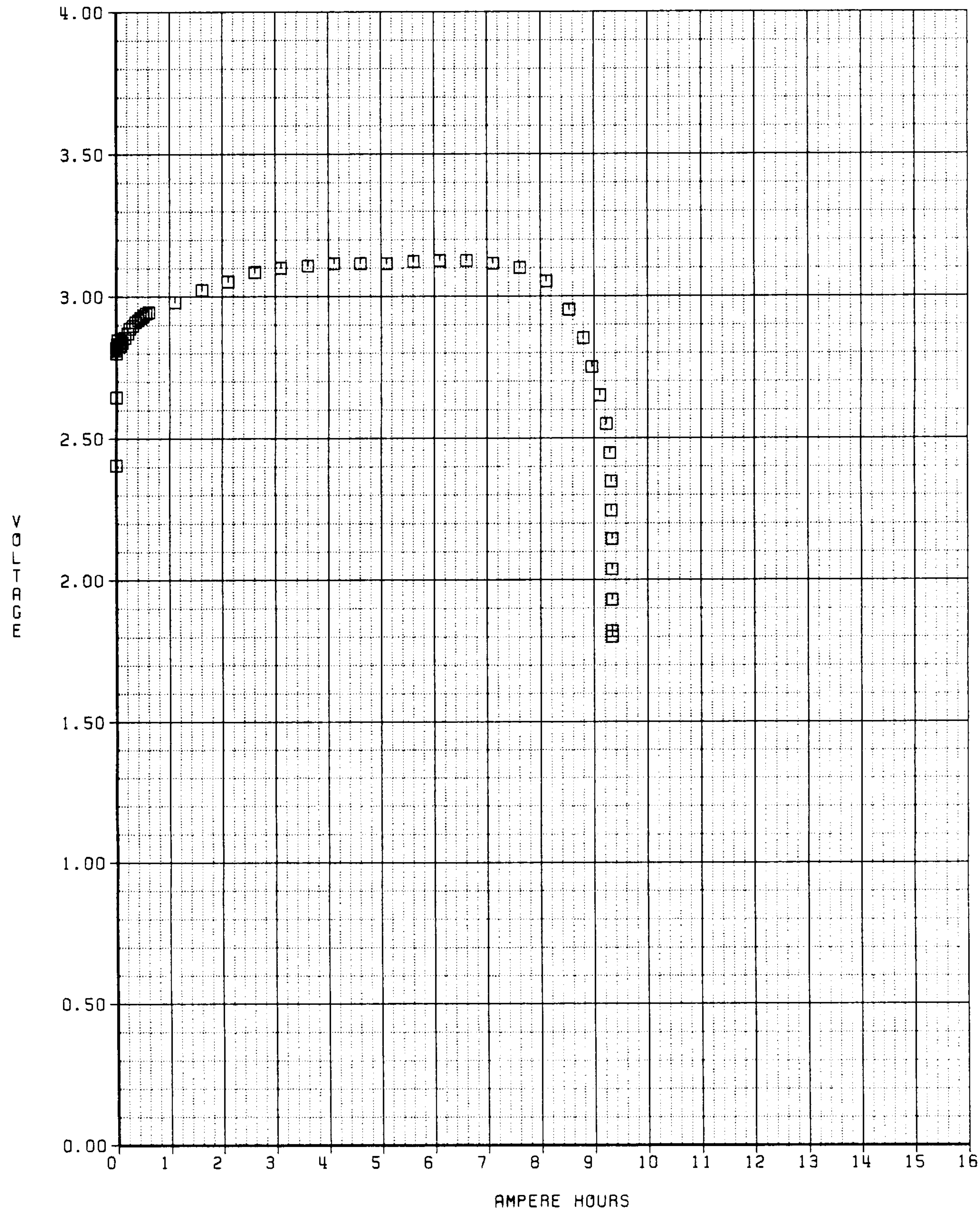

UNIV 1.8M LGC TC D CELL
1 YR STORAGE AT RM TEMP/3 AMP DISCHARGE AT RT
MACCOR3 ID 1215 OF NASA D CELL STUDY
WG
4.00
3.50
3.00
2.50
2.00
1.50
1.00
0.50
0.00
VOLTAGE
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
AMPERE HOURS
GPLOT(REV. 3.5)
DAY 054 TUE, FEB 23 1993 2:45:09 PM

Figure 153

UNIV 0.6M LGC CSC D CELL
1 YR STORAGE AT AM TEMP/3 AMP DISCHARGE AT AT

MACCOR3 ID 1218 OF NASA D CELL STUDY



GPLOT (REV. 3.5)   DAY 054 TUE. FEB 23 1993 2:47:52 PM

Figure 154

JPL 1.8M LGC BCX D CELL
1 YR STORAGE AT RM TEMP/3 AMP DISCHARGE AT RT

MACCOR3 ID 1222 OF NASA D CELL STUDY

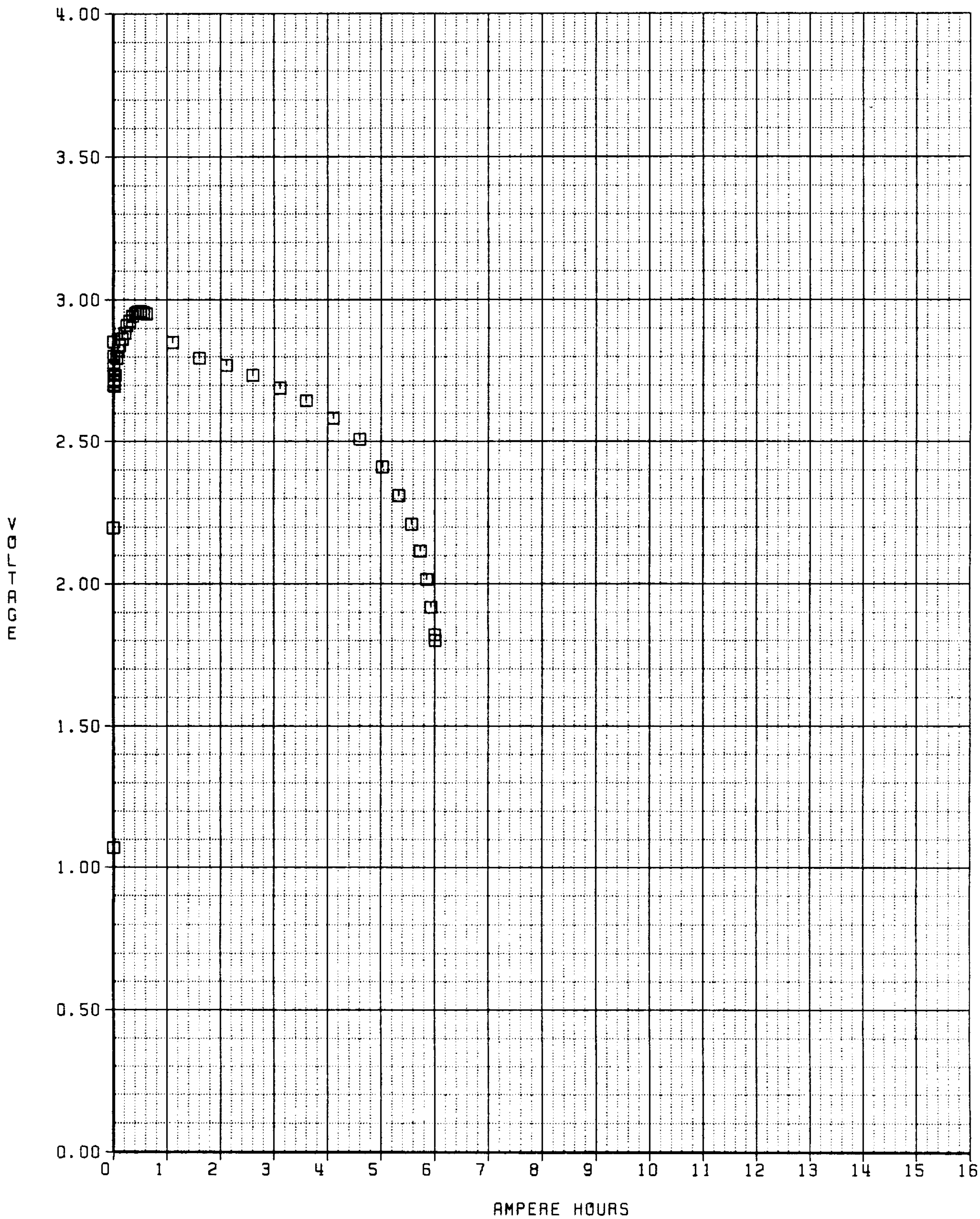
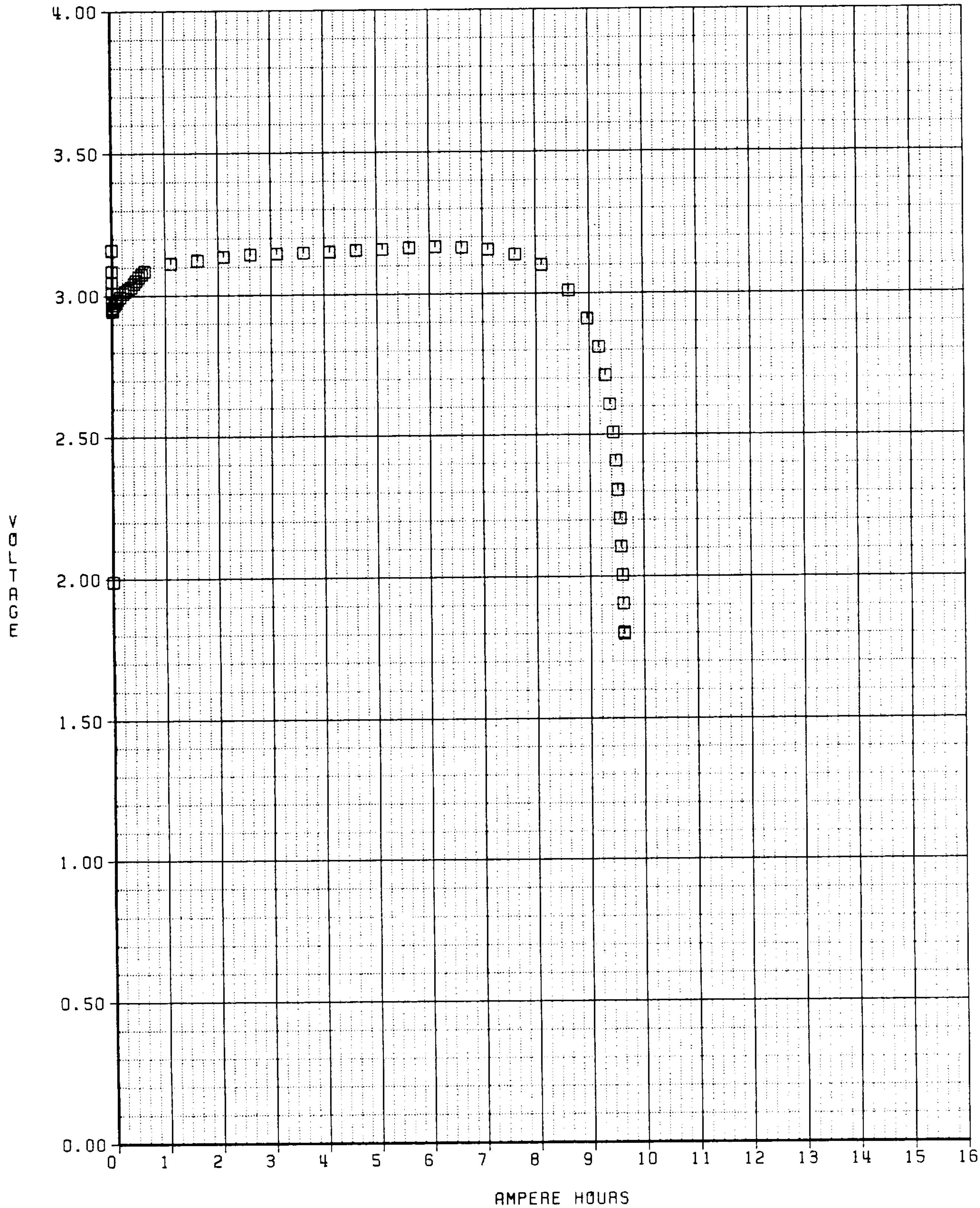


Figure 155

JPL 0.6M LGC TC D CELL
1 YR STORAGE AT RM TEMP/3 AMP DISCHARGE AT RT

MACCOR3 ID 1225 OF NASA D CELL STUDY



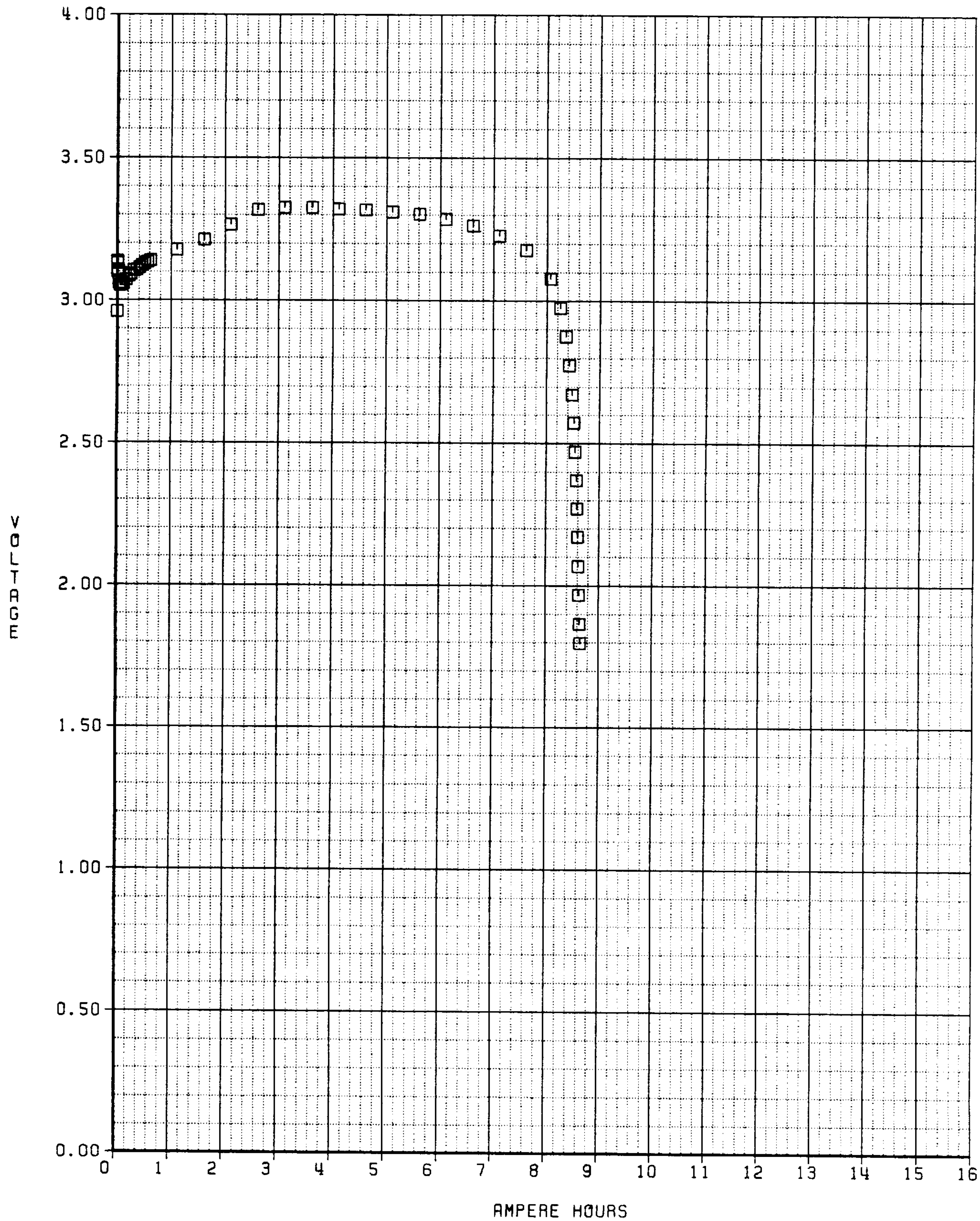
GPLOT (REV. 3.5)

DAY 054 TUE. FEB 23 1993 3:03:28 PM

Figure 156

JPL 1.2M LGC CSC D CELL
1 YR STORAGE AT RM TEMP/3 AMP DISCHARGE AT RT

MACCOR3 ID 1228 OF NASA D CELL STUDY



GPLOT(REV. 3.5)

DAY 054 TUE. FEB 23 1993 3:10:34 PM

The electrolyte concentration has somewhat of an effect on electrical performance. The lower molarity electrolytes typically have better start up characteristics than the high molarity electrolytes. However, the higher molarity electrolytes resulted in higher delivered capacities of fresh cells discharged at high rate. Other performance attributes were not affected by electrolyte concentration to a great extent.

5.7 MICROCALORIMETRY MEASUREMENTS

Microcalorimetry measurements were obtained at room temperature and OCV on fresh cells (29 - 49 days from time of activation), and three times afterwards at approximately three month intervals. The self-discharge current was calculated based on the OCV and the measured heat dissipation, and the effects of the factors on self-discharge rate were analyzed. The ANOVA reports for the four microcalorimetry measurements are located in Appendix H.

In fresh cells the factors affecting self-discharge current were the cell design (18.2% contribution) and the depolarizer type (36.7% contribution). Figure 157 illustrates the effect of the cell design on self-discharge rate. The NASA design has the lowest rate of self-discharge and the JPL design has the highest rate. The effect of the depolarizer on self-discharge rate is seen in figure 158. CSC depolarizer resulted in lower self-discharge rates than BCX, and the TC depolarizer resulted self-discharge rates similar to CSC.

A second microcalorimetry measurement was obtained on cells ranging from 138 - 153 days old. The cell design and the depolarizer type had the largest effects on self-discharge rate contributing 17.5% and 30.7%, respectively. NASA cells had the lowest self-discharge rates of the three designs. Thionyl chloride and CSC depolarizers resulted in similar self-discharge currents (80.11 and 86.94 μA) and BCX resulted in self-discharge currents nearly three times that of TC and CSC (237.94 μA). See figures 159 & 160.

The third microcalorimetry measurement was obtained after 222 - 240 days. Figures 161 - 163 illustrate the effects of the electrolyte type, the cell design, and the depolarizer type on self-discharge rates. The electrolyte type has a 8% effect on self-discharge current, and the LGC electrolyte produces lower rates of self-discharge than the LAC electrolyte. The cell design contributes 17.7% to the variation in self-discharge rate, and the NASA design has the lowest rate of the three designs. The depolarizer type is the second most important factor in determining self-discharge rate of 8 month old cells, contributing 13.6% to performance variation. Again, the TC and CSC depolarizers result in significantly lower self-discharge rates

Figure 157

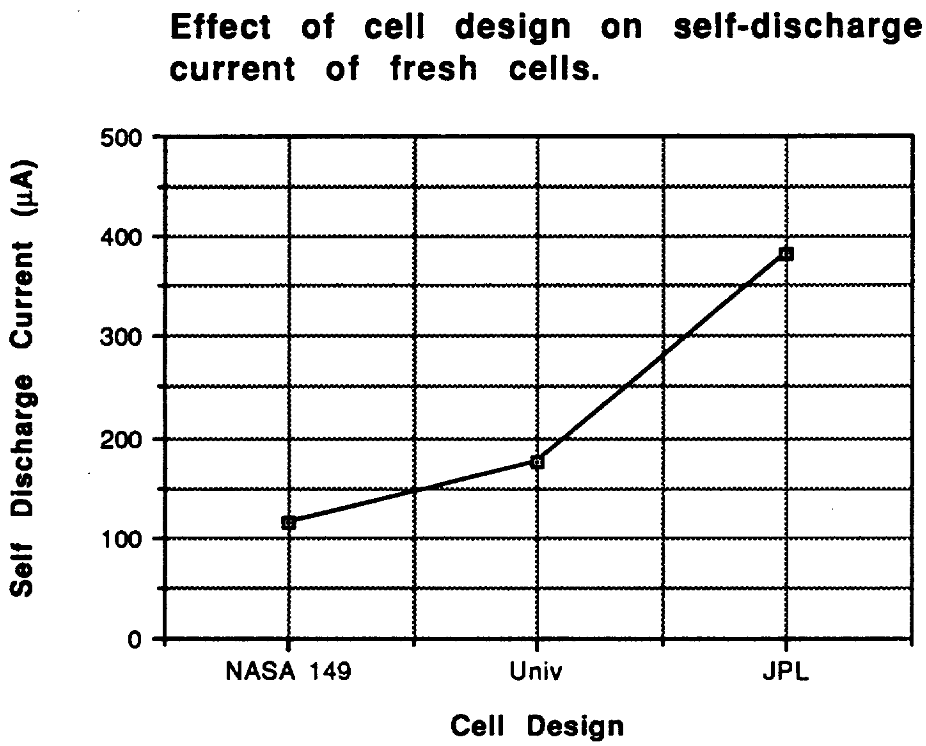

Effect of cell design on self-discharge current of fresh cells.
Self Discharge Current (µA)
500
400
300
200
100
0
NASA 149
Univ
JPL
Cell Design

Figure 158

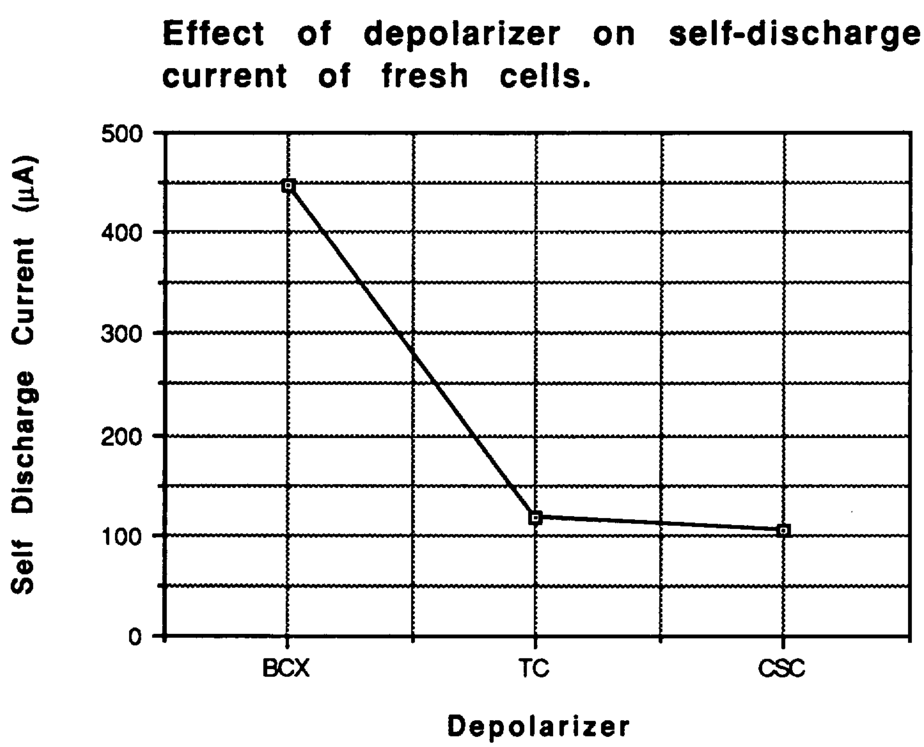

Effect of depolarizer on self-discharge current of fresh cells.
Self Discharge Current (μA)
500
400
300
200
100
0
BCX
TC
CSC
Depolarizer

Figure 159

Effect of cell design on self discharge current as measured by microcalorimetry after 4.5 months at room temperature.

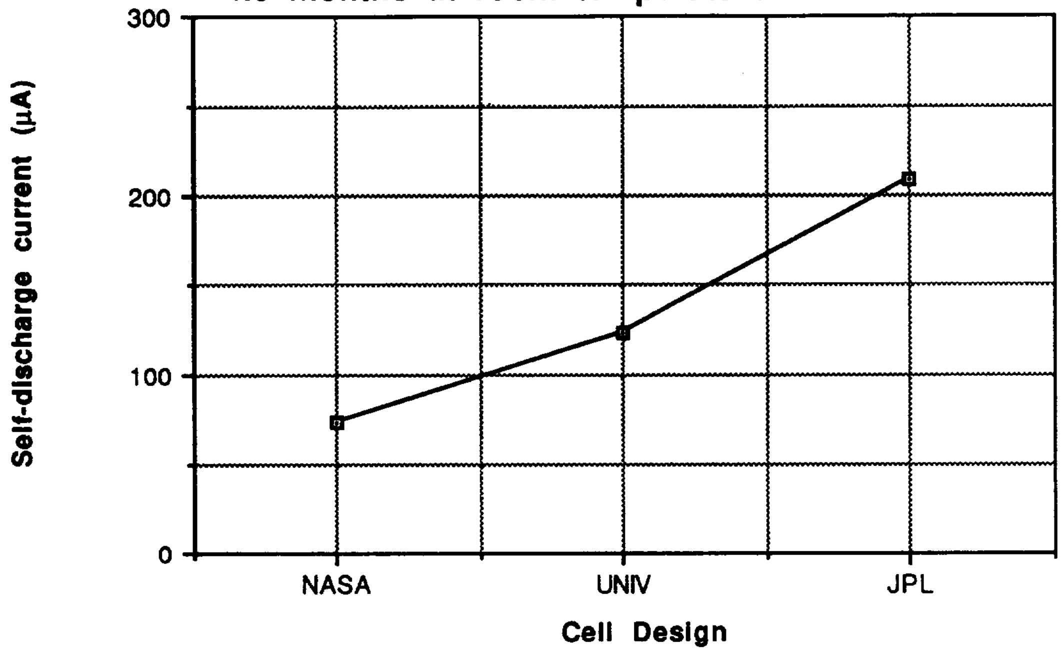


Figure 160

Effect of depolarizer type on self discharge current as measured by microcalorimetry after 4.5 months at room temperature.

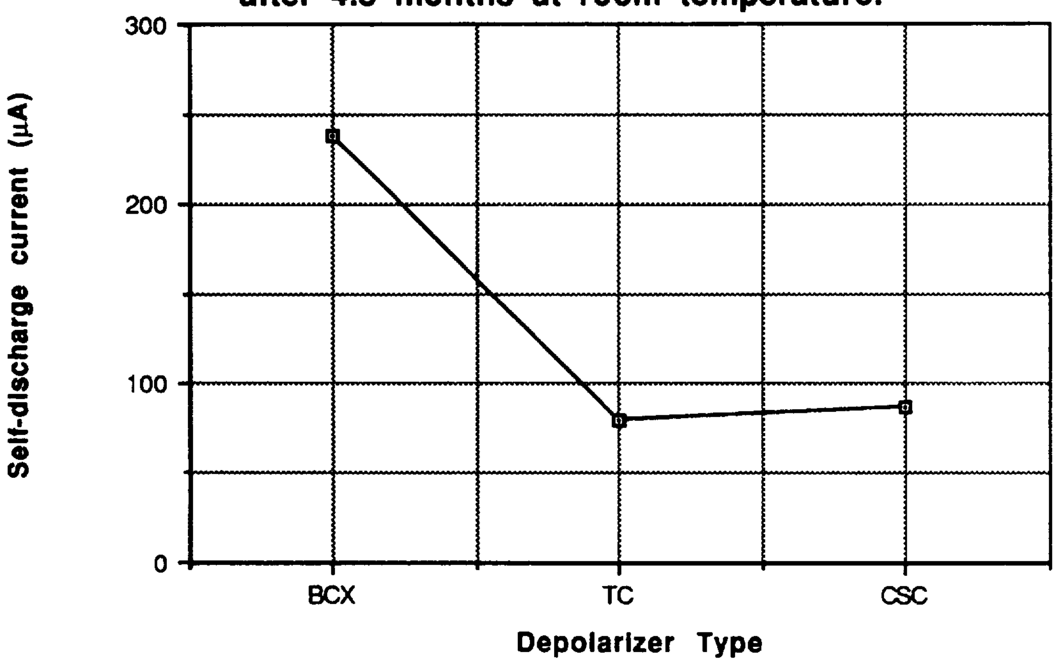


Figure 161

Effect of electrolyte type on self-discharge current as measured by microcalorimetry after 8 months at room temperature.

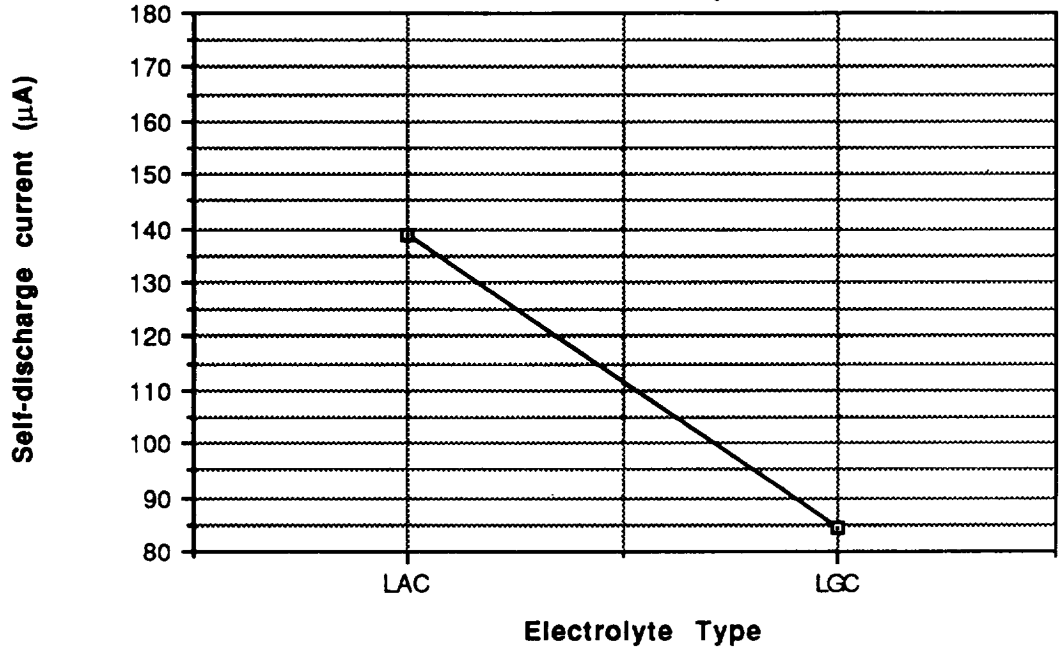


Figure 162

Effect of cell design on self-discharge current as measured by microcalorimetry after 8 months at room temperature.

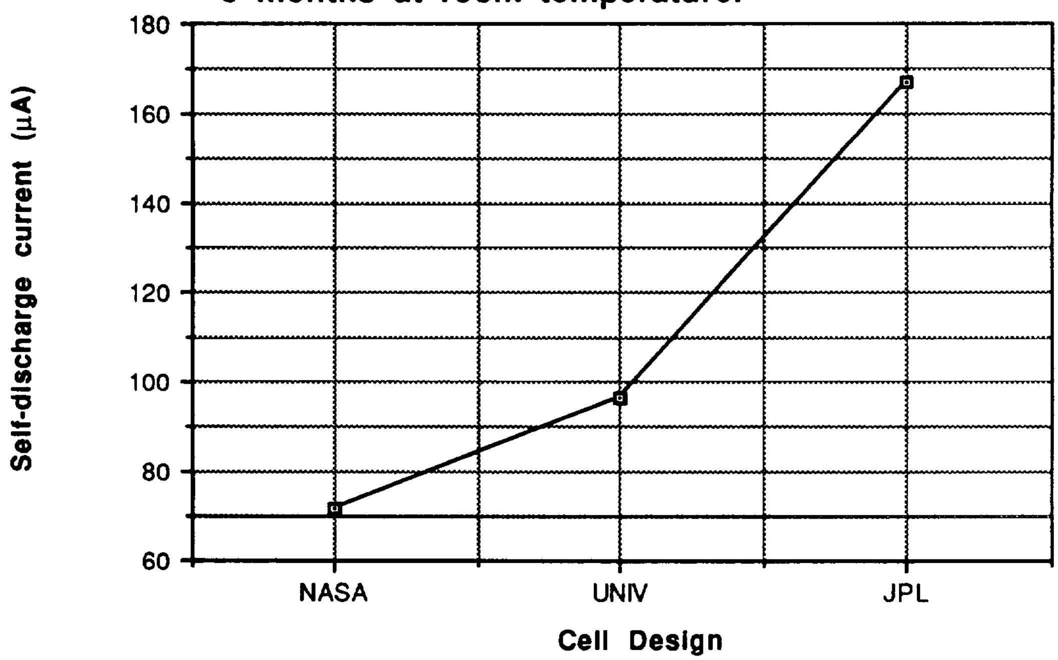
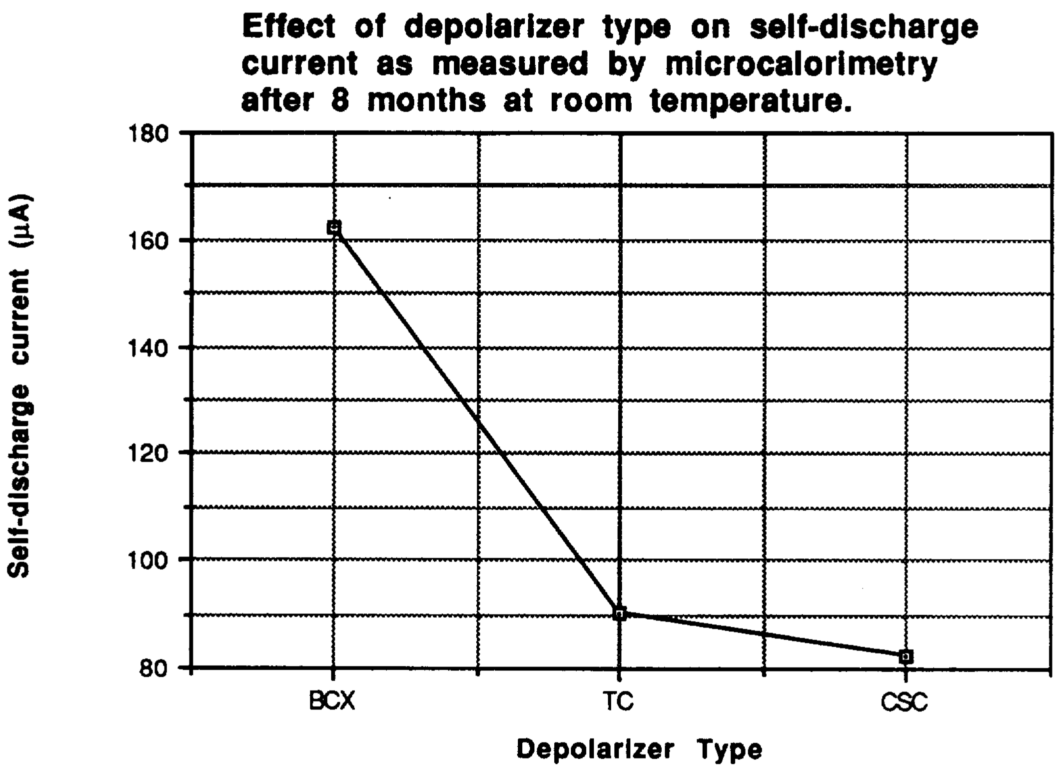


Figure 163


Effect of depolarizer type on self-discharge current as measured by microcalorimetry after 8 months at room temperature.
Self-discharge current (µA)
180
160
140
120
100
80
BCX
TC
CSC
Depolarizer Type

than the BCX depolarizer.

The fourth and final microcalorimetry measurement was obtained after 354 - 370 days from time of activation. The factors affecting self-discharge current were electrolyte type and cell design, contributing 10.5% and 16.6% to the variation in self-discharge current, respectively. The depolarizer contributed only 4.6% to the variation in self-discharge rates of one year old cells. Figures 164 & 165 show the effects of the electrolyte type and the cell design. Self-discharge currents for cells with LGC electrolyte are at an average of 72.3 μA and at 133.5 μA for cells with LAC electrolyte. The NASA and UNIV cells have significantly lower self-discharge rates than the JPL cells.

SUMMARY OF MICROCALORIMETRY DATA

The electrolyte type plays only a small role in determining self-discharge rates of aged Li/oxyhalide cells. In cells that are 8 months or older, those with LGC electrolyte have lower self-discharge currents than those with LAC electrolyte.

The cell design affects self-discharge rates in fresh cells as well as those aged up to 1 year. The NASA design offers lower self-discharge currents than the other two designs for the first 8 months. After 1 year the NASA design is only slightly better than the UNIV design, but significantly better than the JPL design.

The depolarizer type affects self-discharge rates of cells aged up to 8 months. TC and CSC depolarizers have lower self-discharge rates than the BCX depolarizer. After 1 year storage, the depolarizer has no effect on self-discharge rates.

The electrolyte concentration had no effect on self-discharge currents for any of the four measurements.

5.8 TEMPERATURE TOLERANCE TESTING

Maximum cell temperature tolerance was determined for each configuration, both at a full state of charge and completely discharged. The cells were initially subjected to temperatures of 139°C and held at that temperature for 15 minutes. The cells were allowed to cool to a temperature of ≤ 50°C and visually examined for any evidence of electrolyte leakage, cell venting, rupturing or explosion. The glass to metal seal area and the weld were checked utilizing moistened litmus paper to verify that no electrolyte leakage occurred. This process was repeated at temperatures of 149°C and 159°C.

Data analysis by the Taguchi method does not apply well for this performance attribute. This is because the maximum cell temperature tolerance is largely a function of how well we set and

Figure 164

Effect of electrolyte type on self-discharge current as measured by microcalorimetry after 1 year at room temperature.

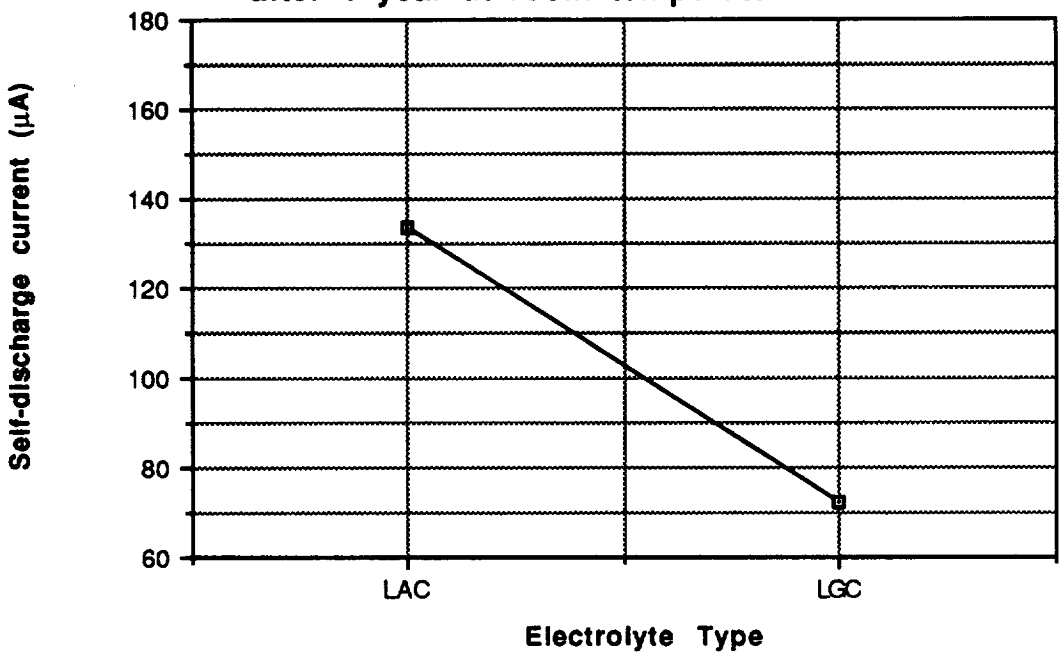
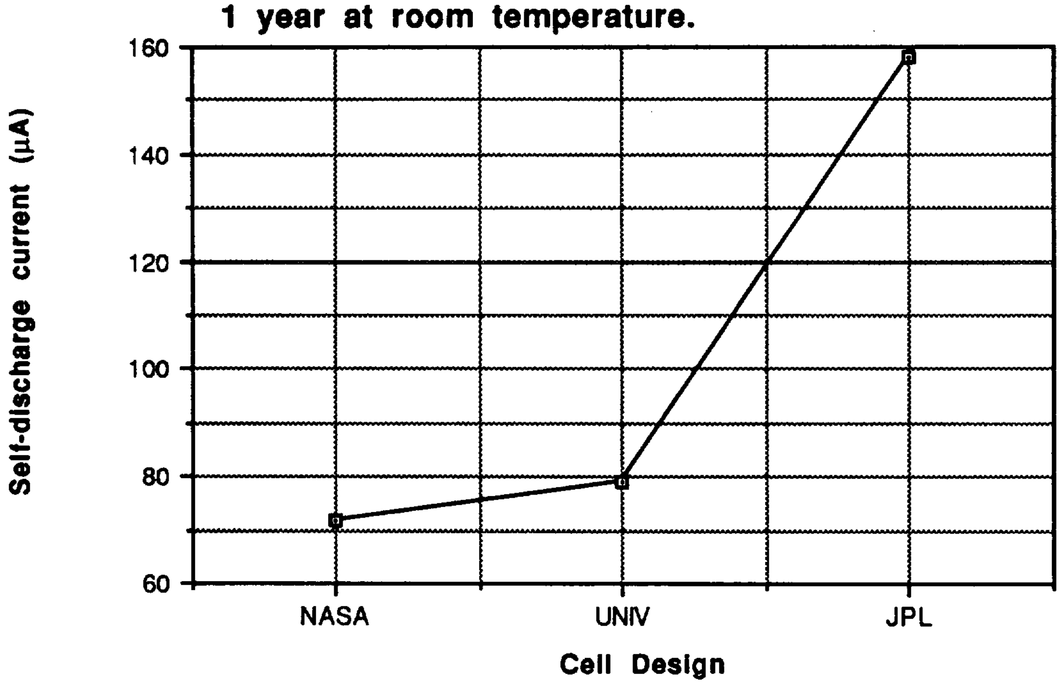


Figure 165

Effect of cell design on self-discharge current as measured by microcalorimetry after 1 year at room temperature.



maintain the internal void volume of a cell, rather than a function of the factors studied in this effort. All cells in this experiment were fabricated with a theoretical maximum temperature tolerance of 149°C simply by adjusting the void volume of each configuration. Therefore, the optimized cell design chosen on the basis of this study can be configured to be tolerant to 149°C. While the Taguchi approach can not be utilized for this test, some observations can be made.

Fifty four fresh cells were exposed to temperatures of 139, 149, and 159°C. After the 139°C exposure, five cells exhibited slight case swelling. Four of these cells were JPL cells and one was a NASA cell, and all five cells contained CSC depolarizer. Five cells swelled as a result of 149°C exposure. Four of these cells were UNIV cells and one was a JPL cell. Three cells configured as JPL/CSC cells vented and/or leaked as a result of 159°C exposure and two NASA/CSC cells bulged.

Similarly, fifty four depleted cells were subjected to the same temperature exposure regimen. None of the cells vented or leaked as a result of high temperature exposure up to 159°C. However, fifteen cells exhibited case swelling after 149°C exposure. Six of these were JPL cells with CSC depolarizer. Five cells were UNIV cells with CSC depolarizer, three were NASA cells with CSC depolarizer, and one cell was a UNIV cell with TC depolarizer.

6.0 ABUSE TESTING

Abuse testing was performed on each D cell configuration to determine the effect of the four factors on safety performance of Li/oxyhalide cells. The testes performed were forced overdischarge (FOD) and variable rate short circuit testing.

Constant current FOD was conducted at 25±5°C at rates of 1A and 3A. The FOD test was carried out on cells previously discharged for this contract which remained dormant for 3±1 weeks since completion of discharge tests. The 1A test was conducted both with and without by-pass diodes for a period of 16 hours under each condition. Similarly, the 3A test was conducted for 5 hours at each condition. ANOVA analysis was conducted on the basis of a rating system which was developed to assess the physical change in cell containment as a result of FOD.

High current shorting tests were conducted at three rates through an external resistor. This test was modelled after the testing conducted for the Hazard Definition Study, Modification 5, NAS 9-18395. Appendix I describes the testing procedure, the system calibration, the cell and circuit energy calculations, and the physical properties of the oil used. The resistive loads were determined based the ability of all cells in the study to carry the loads for the duration of the test without a destructive

event. The loads used were 2Ω, 0.700Ω and 0.325Ω, and generated currents between 1.5 and 8.5A. The heat output of the cells was determined by immersing the cells in a heat sinking liquid of known heat capacity contained in a thermally insulated container (also of known heat capacity) and measuring the temperature rise of the liquid over the duration of the test. The heat dissipated by each cell during the test was then calculated and an ANOVA analysis was conducted.

6.1 FORCED OVERDISCHARGE AT 1A

Fifty four D cells were FOD tested at 1A and 25°C for 16 hours with by-pass diodes after a 3±1 week dormant period after completion of discharge. Only one of the fifty four cells experienced a change in containment and vented as a result of this test. It was later determined that the cell vented as a result of both a manufacturing defect and the loss of the diode during the test. Destructive analysis indicated that the cell developed a hot spot as a result of lithium overlap at the end of the wound assembly. This phenomenon combined with the loss of the protective diode resulted in heat build up and subsequent venting of the cell. It is therefore concluded that the vent was due to the manufacturing defect in the cell and is not related to cell design or chemistry. The remaining fifty three cells experienced no change in cell containment.

The fifty three remaining cells were FOD tested at 1A and 25°C for a period of 16 hours without by-pass diodes. Many of the cells could not carry the current for the duration of the 16 hour test, if at all. In order to conduct the ANOVA analysis for this portion of the testing, a ranking system was devised based on the relative change in physical containment of the cell. The cells were ranked from 1 - 6 as follows: 1) no change, 2) heat stain, 3) bulge, 4) leak, 5) vent, and 6) rupture. The Reliability Report 92-066 is included in Appendix J, and the ANOVA report is included in Appendix K. Three cells vented during test, one leaked and the remaining were quite benign. The ANOVA report shows that the majority of the variability in physical change is due to outside noises (58.1%). The cell design and the depolarizer type have the largest effects of the four factors (16.9% and 17.8% respectively). JPL cells exhibited the least amount of physical change during the test as did cells with BCX depolarizer.

6.2 FORCED OVERDISCHARGE AT 3A

Fifty four D cells were FOD tested at 3A and 25°C with by-pass diodes for 5 hours after a 3 week dormant period. There was no physical change in any of the cells as a result of this test.

Subsequent FOD testing at 3A and 25°C was done for 5 hours without by-pass diodes. The same ranking system developed for the 1A FOD

test was employed to assess the level of physical change in cell containment. Two of the cells in the study ruptured as a result of this test, seven vented, and one leaked. The ANOVA analysis, included in Appendix L, indicated that the majority of the variability in physical change is due to outside noises (51.9%). The cell design contributed 26.7% to the variability in physical change, and the JPL cells change the least as a result of this test. Appendix M includes the Reliability Report (#92-080) for this portion of the testing.

6.3 SHORT CIRCUIT TESTING AT 2Ω

Eighteen D cells were short circuited under 2Ω loads to determine the heat dissipated under shorting conditions. Three response variables were determined and analyzed. These were the total energy in Joules, the delivered capacity in Ah, and the heat generated as a function of capacity in J/Ah. These three attributes were chosen in order to fully understand the effects of the four factors on heat output and to better explain the reasons behind the relationship between the factors and cell performance.

Appendix N contains the ANOVA analysis for the 2Ω short circuit data. The factor having the largest effect on heat generated (excluding outside noises) is the depolarizer type which contributes 33.9% to the variation in dissipated energy. BCX and TC depolarizers result in the lowest amounts of heat output as compared to CSC depolarizer. Figure 166 illustrates the effect of depolarizer on this performance attribute. Figure 168 illustrates the effect of the electrolyte type on heat dissipation, which contributes 14.6% to the variation. Cells with the LAC electrolyte generated less heat as a result of 2Ω short circuit than cells with the LGC electrolyte. The other two factors had less than a 2% effect on heat dissipation, and their main effects are illustrated in figures 167 & 169.

The delivered capacity under 2Ω loads was also analyzed. Figures 170 - 173 illustrate the main effects of the four factors on capacity. The depolarizer has the largest effect on capacity (37.0%) and the cells with CSC depolarizer delivered the highest capacities of the three depolarizers. (See figure 172.) The electrolyte type has a small effect on capacity (7.6%). However, the cells with LGC electrolyte delivered higher capacities than the cells with LAC electrolyte.

This brings us to the relationship between the heat generated and the delivered capacity of D cells, and the effect of the four factors on this last attribute. Figures 174 - 177 illustrate these effects. The electrolyte type contributes 10.4% to the variation in heat dissipated per Ah capacity. Figure 174 shows that the LGC electrolyte results in less heat dissipation per capacity unit than the LAC electrolyte. The cell design has no

Figure 166

Effects of depolarizer type on heat generated in D cells under 2Ω loads.

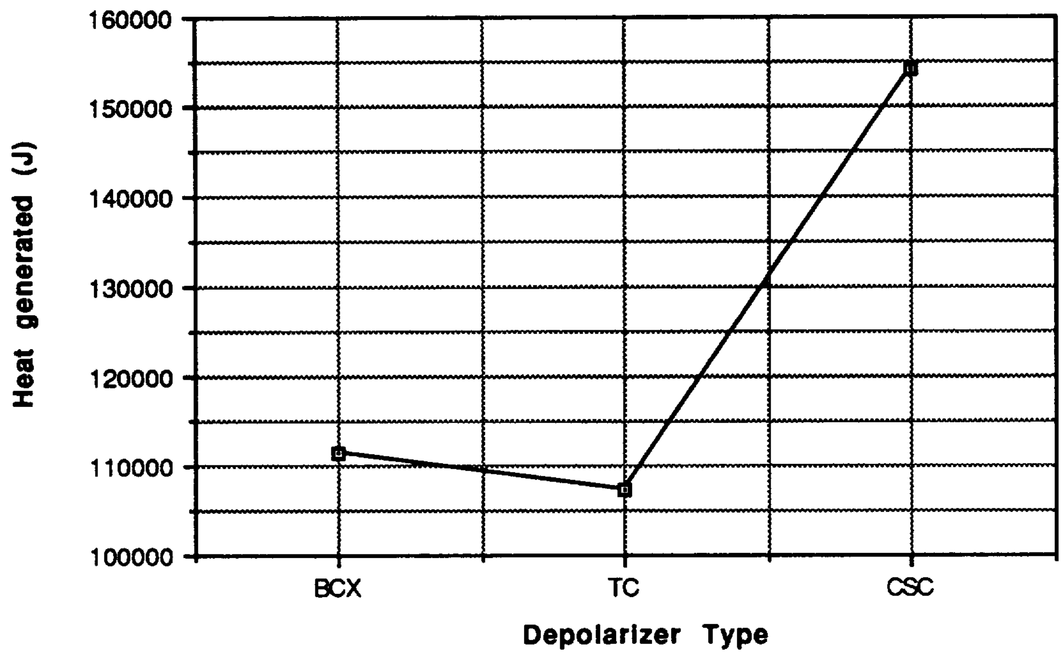


Figure 167

Effects of electrolyte concentration on heat generated in D cells under 2Ω loads.

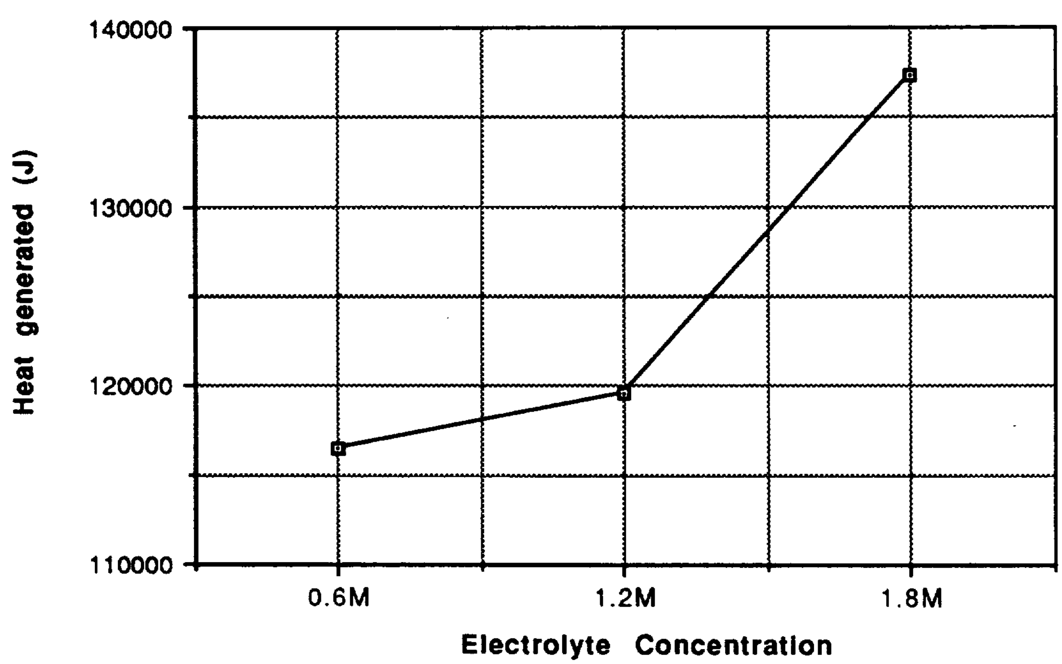


Figure 168

Effect of electrolyte type on heat generated in D cells under 2Ω loads.

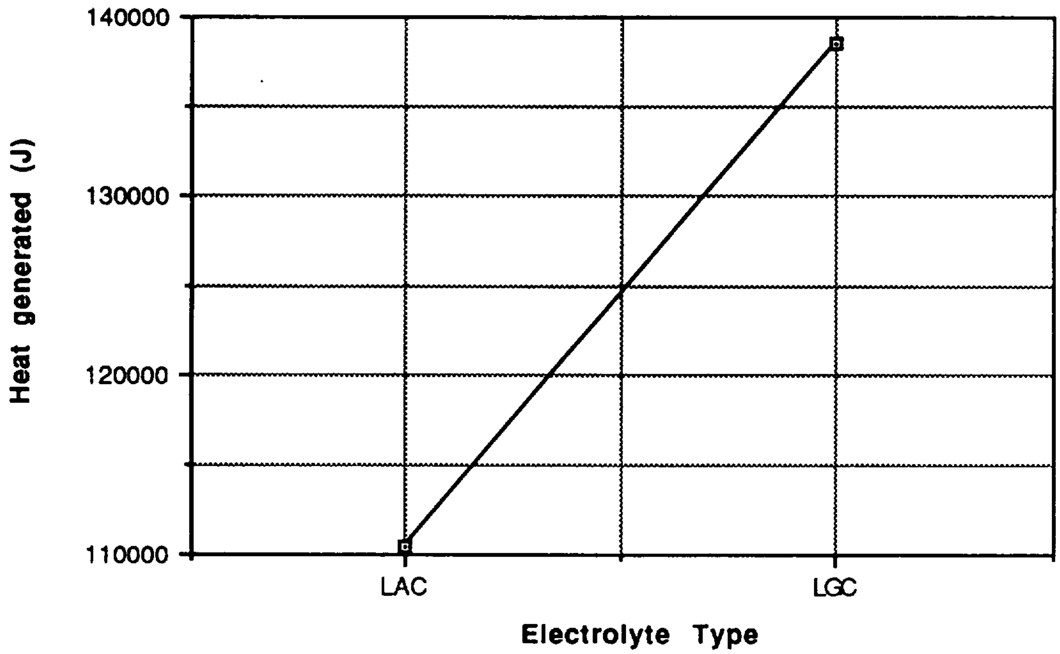


Figure 169

Effects of cell design on heat generated in D cells under 2Ω loads.

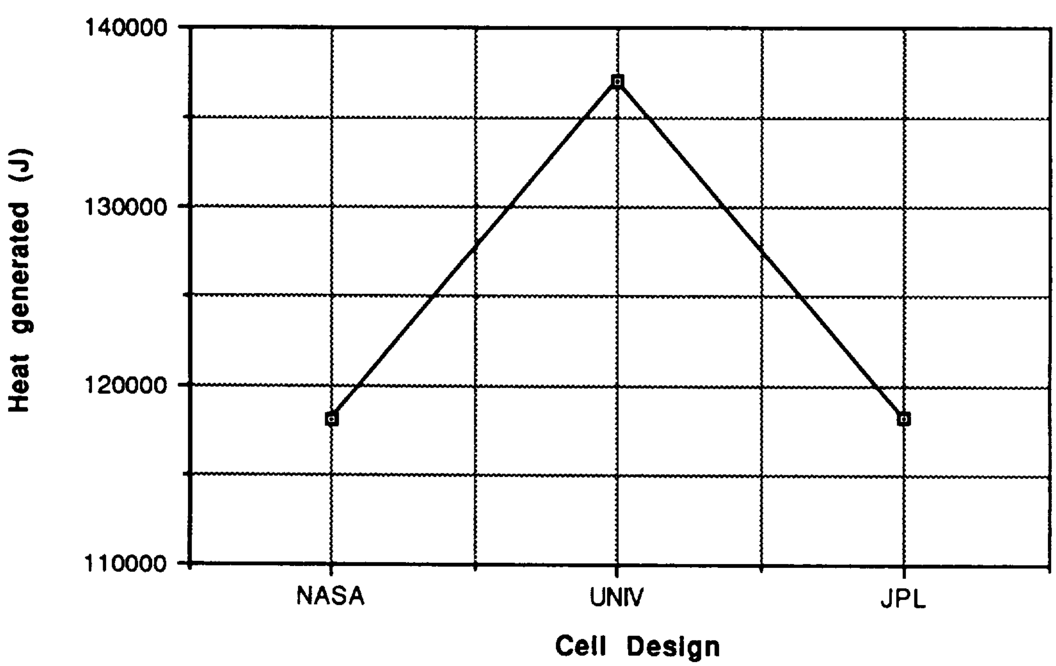


Figure 170

Effect of electrolyte type on capacity of D cells under 2Ω loads.

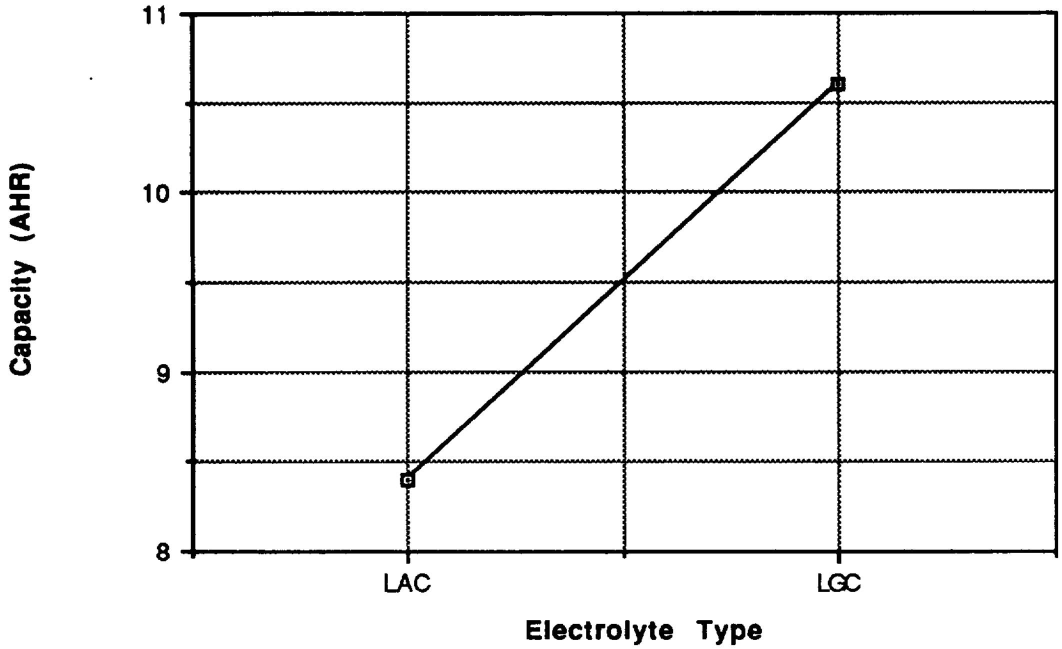


Figure 171

Effect of cell design on capacity of D cells under 2Ω loads.

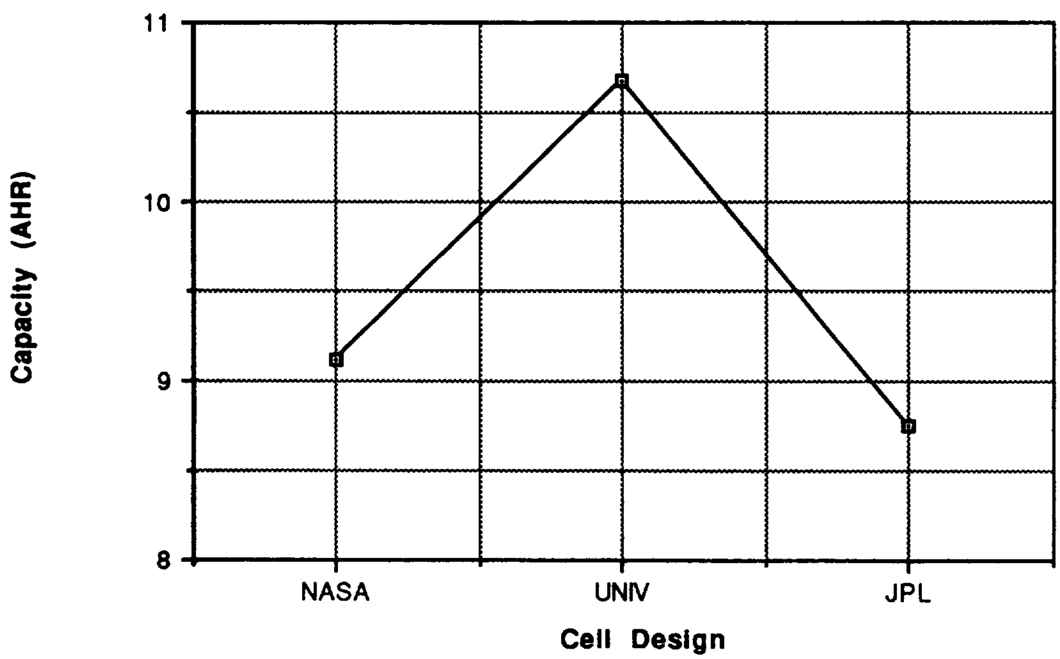


Figure 172

Effect of depolarizer type on capacity of D cells under 2Ω loads.

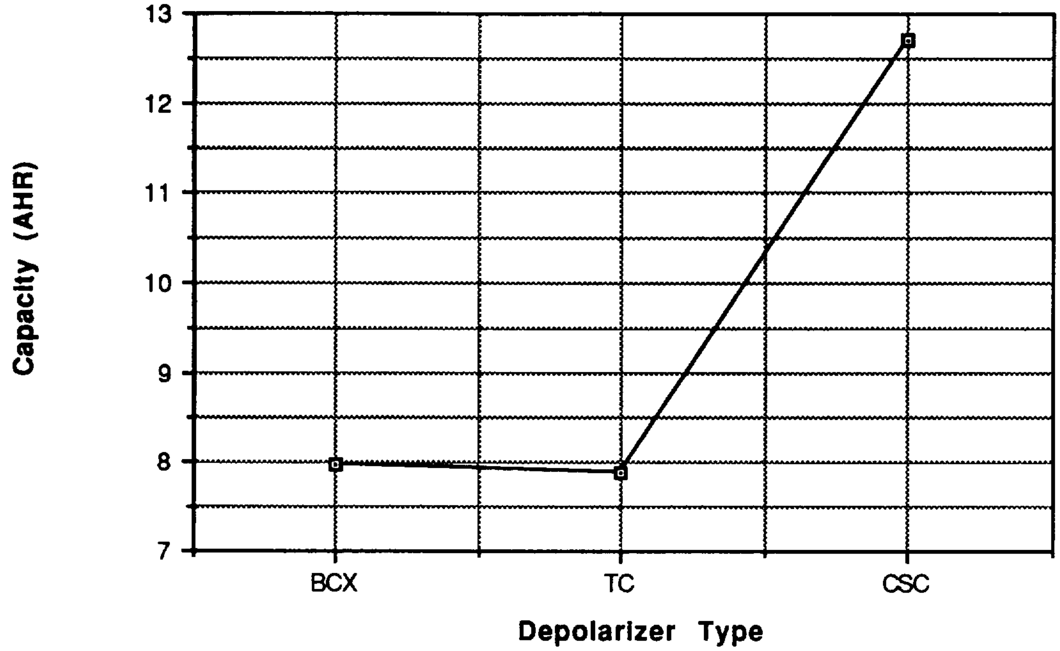


Figure 173

Effects of electrolyte concentration on capacity of D cells under 2Ω loads.

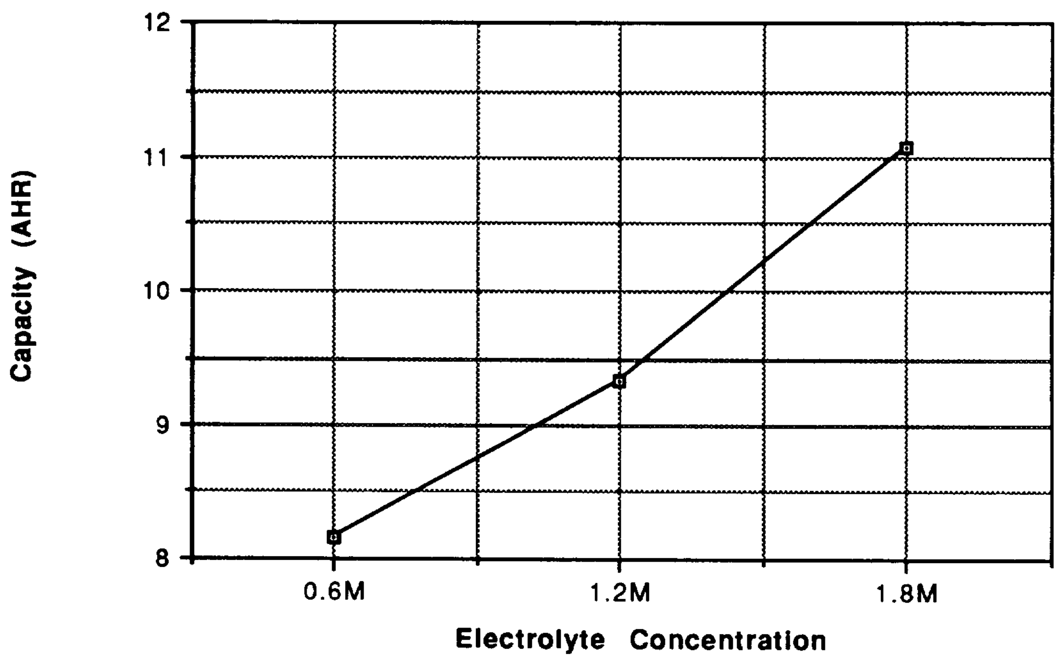


Figure 174

Effect of electrolyte type on heat generated per Ahr under 2Ω loads.

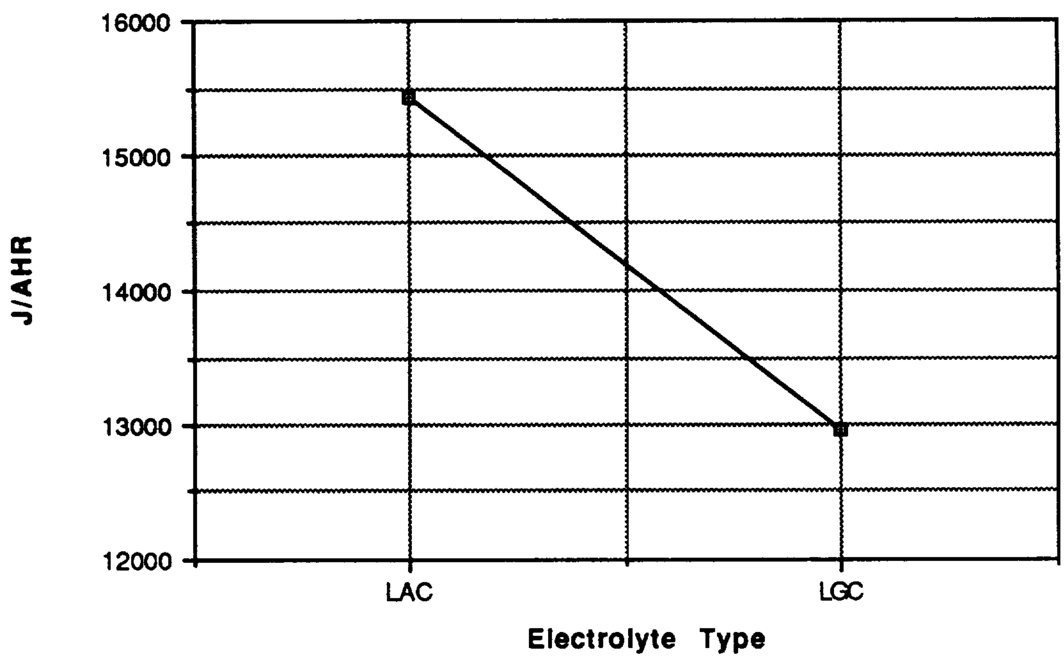


Figure 175

Effect of cell design on heat generated per Ahr under 2Ω loads.

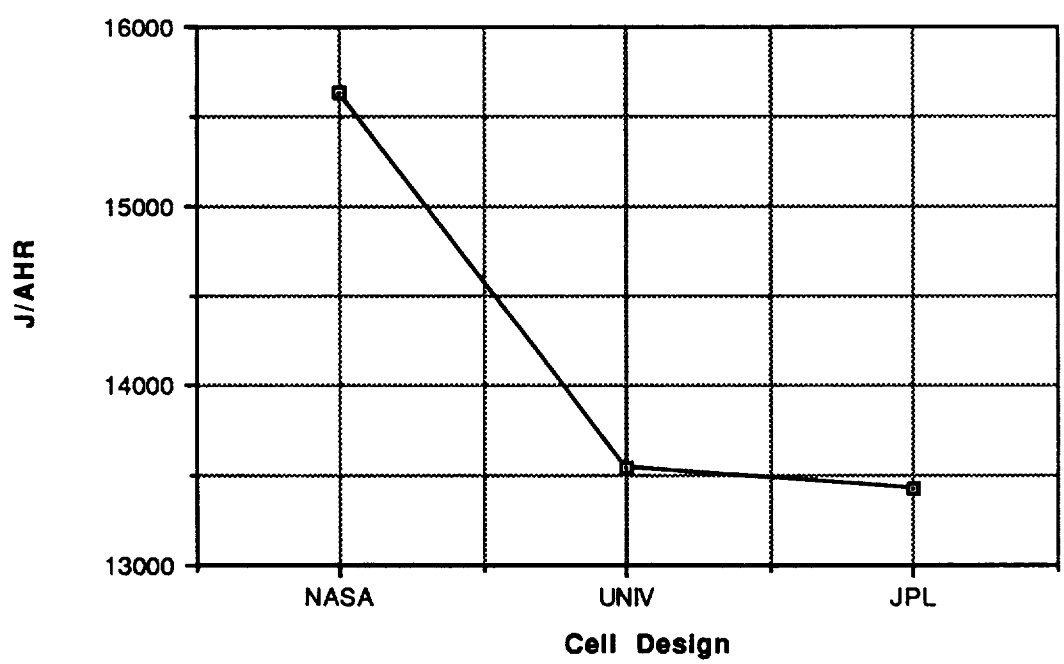


Figure 176

Effect of depolarizer on heat generated per Ahr under 2Ω loads.

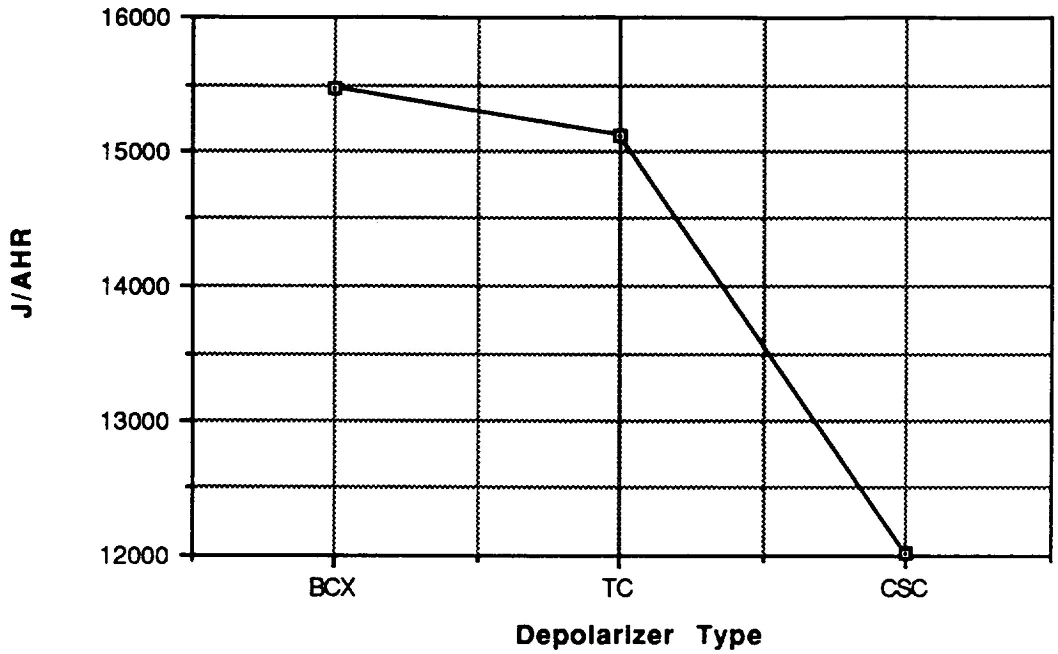
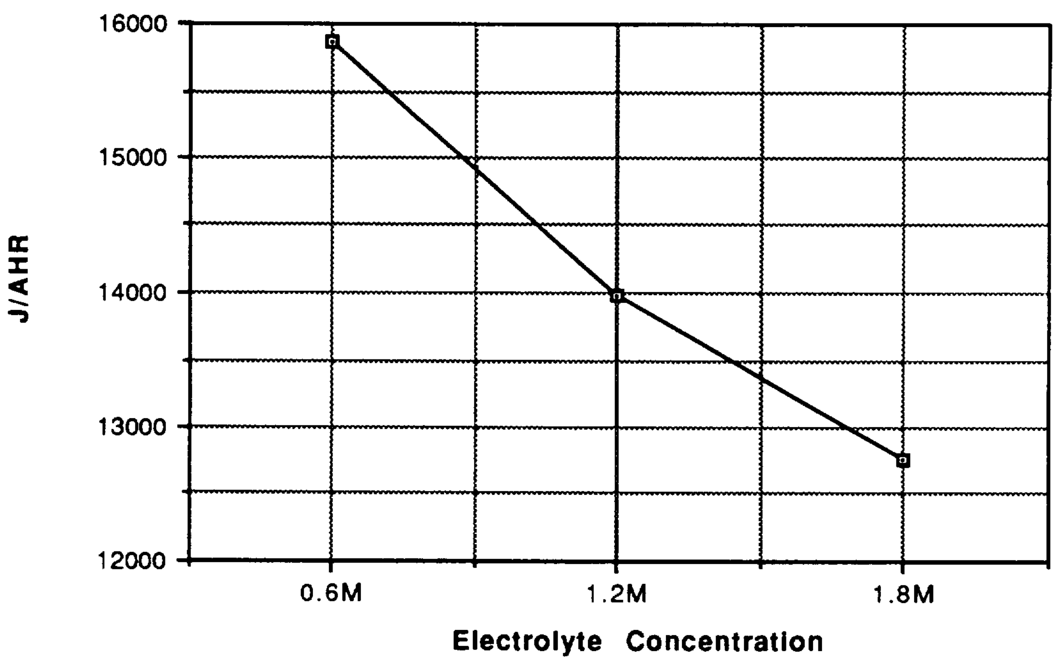


Figure 177

Effects of electrolyte concentration on heat generated per Ahr under 2Ω loads.



consequence on this attribute and the depolarizer contributes 14.8%. The CSC depolarizer results in less heat dissipated per Ah of capacity delivered than the other two depolarizers. The electrolyte concentration has only a small effect (7.6%), and the trend is toward higher molarity electrolyte.

6.4 SHORT CIRCUIT TESTING AT 0.7Ω

Eighteen D cells were short circuit tested at 0.7**Ω** to assess the heat dissipation as a function of shorting rate. At this rate the factor having the largest effect, disregarding outside noise, was the depolarizer type, contributing 32.2% to the variation in heat dissipation. Figure 178 illustrates the effect of depolarizer on this attribute, and indicates that the CSC depolarizer results in the highest amount of heat generated. Both BCX and TC have low levels of heat dissipation. The electrolyte concentration contributes 16% to the overall variation in heat dissipation and the low molarity electrolyte is favored. (See figure 179). figure 180 illustrates the effect of electrolyte type on heat dissipation, which only contributes 6.8% to variation in heat dissipation. The cells with LGC electrolyte generate more heat then the cells with LAC electrolyte. Figure 181 shows the effect of the cell design on heat dissipation, which has no effect on this attribute. Appendix O includes the ANOVA reports for the three response variables analyzed for cells short circuited at 0.7**Ω**.

The delivered capacity in Ah was determined and the effects of each factor analyzed. The two factors playing the largest role in determining the capacity of D cells were the depolarizer and the electrolyte concentration, contributing 34% and 15% to variation in capacity, respectively. BCX and TC depolarizers resulted in capacities of about 7 Ah and CSC depolarizer resulted in an average of 12 Ah during the 0.7**Ω** test. The high molarity electrolyte resulted in the highest delivered capacities, and the relationship between the electrolyte concentration and delivered capacity is fairly linear. (See figures 182 & 183). Figures 184 & 185 show the effects of the electrolyte type and design type on delivered capacity at 0.7**Ω**. The electrolyte type contributes 5.5% to the variation in capacity and the design type has no effect on delivered capacity at this rate.

The relationship between delivered capacity and heat dissipation was calculated in J/Ah and the effects of the four factors were determined. 61% of the variation in this attribute are due to outside noises in the experiment. The depolarizer type and the electrolyte concentration are the only factors affecting the variation in heat dissipation per Ah delivered capacity. CSC depolarizer has the lowest generated heat to delivered capacity ratio (12334.7 J/Ah) of the three depolarizers studied. The high molarity electrolyte also has a low heat to capacity ratio of

Figure 178

Effects of depolarizer type on heat generated in D cells under 0.7Ω loads.

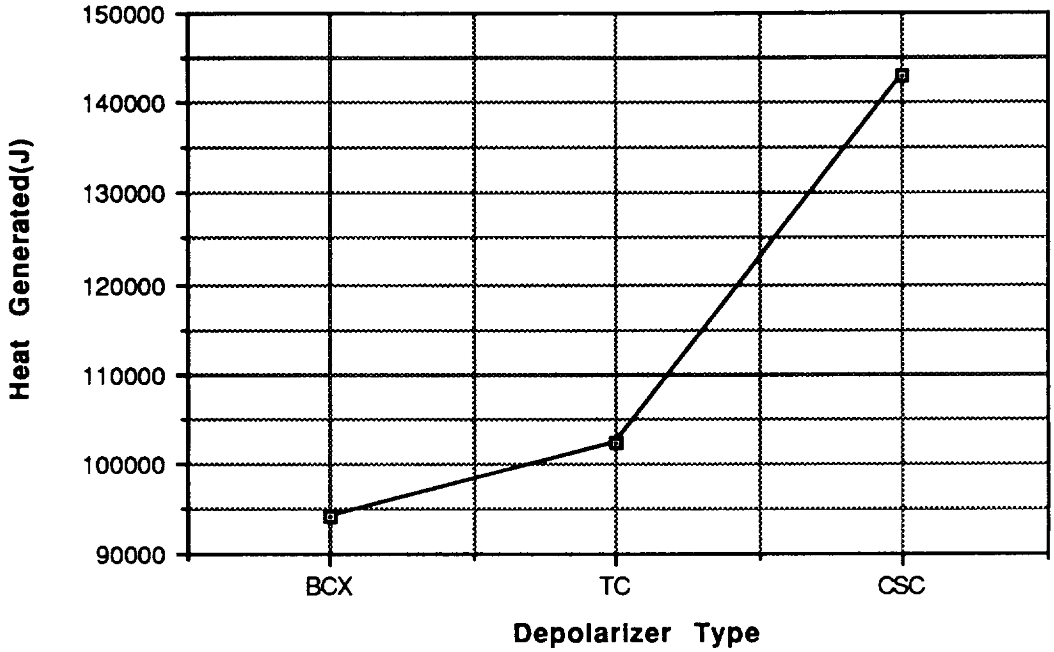


Figure 179

Effects of electrolyte concentration on heat generated in D cells under 0.7Ω loads.

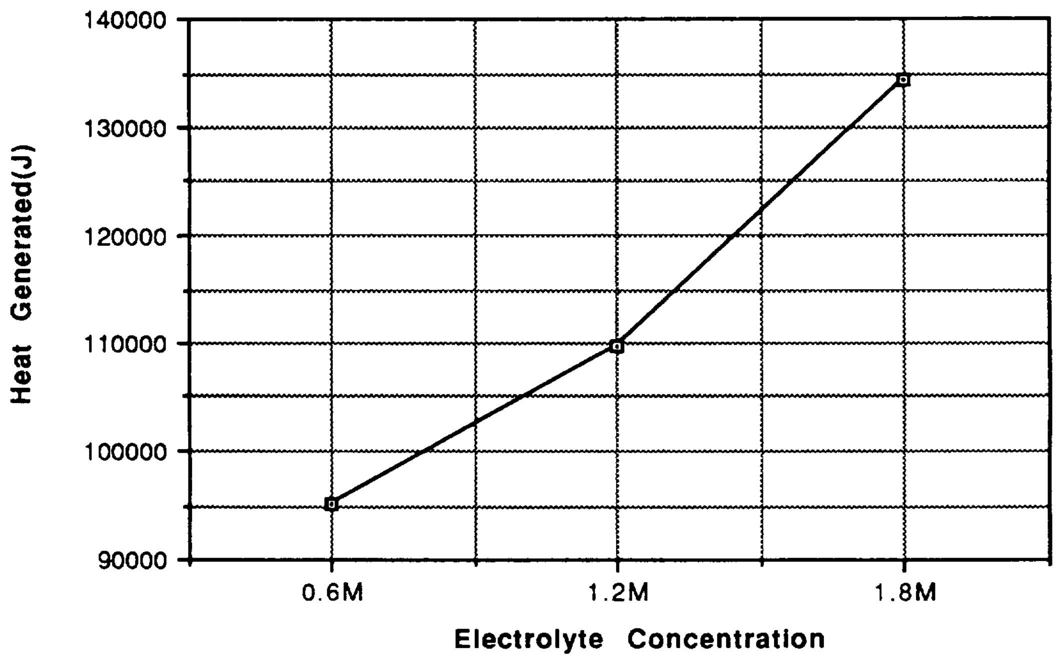


Figure 180

Effects of electrolyte type on heat generated in D cells under 0.7Ω loads.

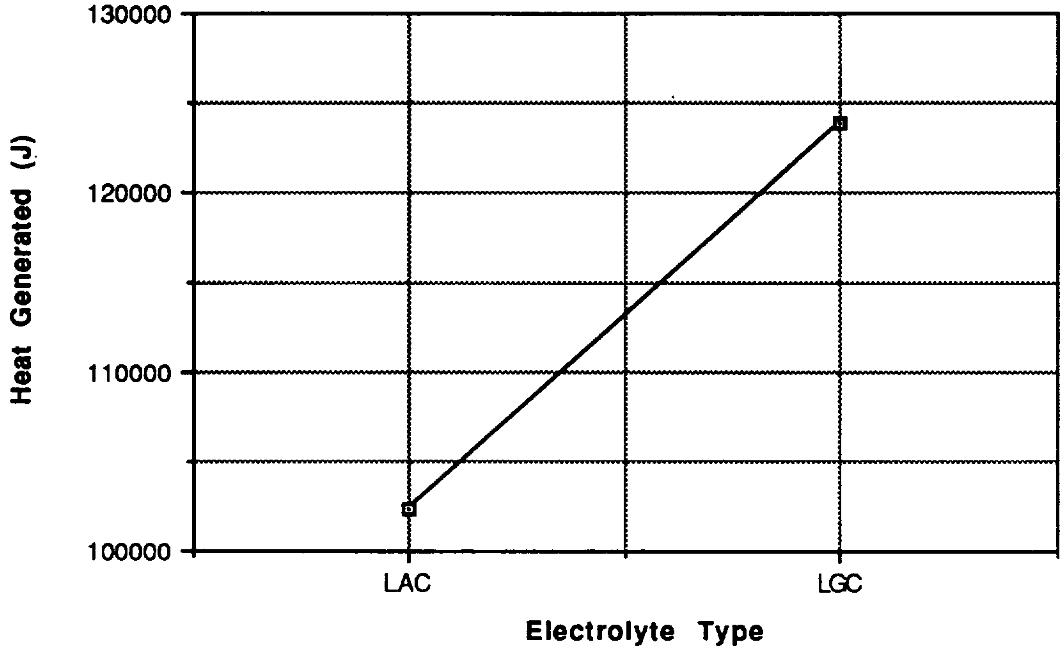


Figure 181

Effects of cell design on heat generated in D cells under 0.7Ω loads.

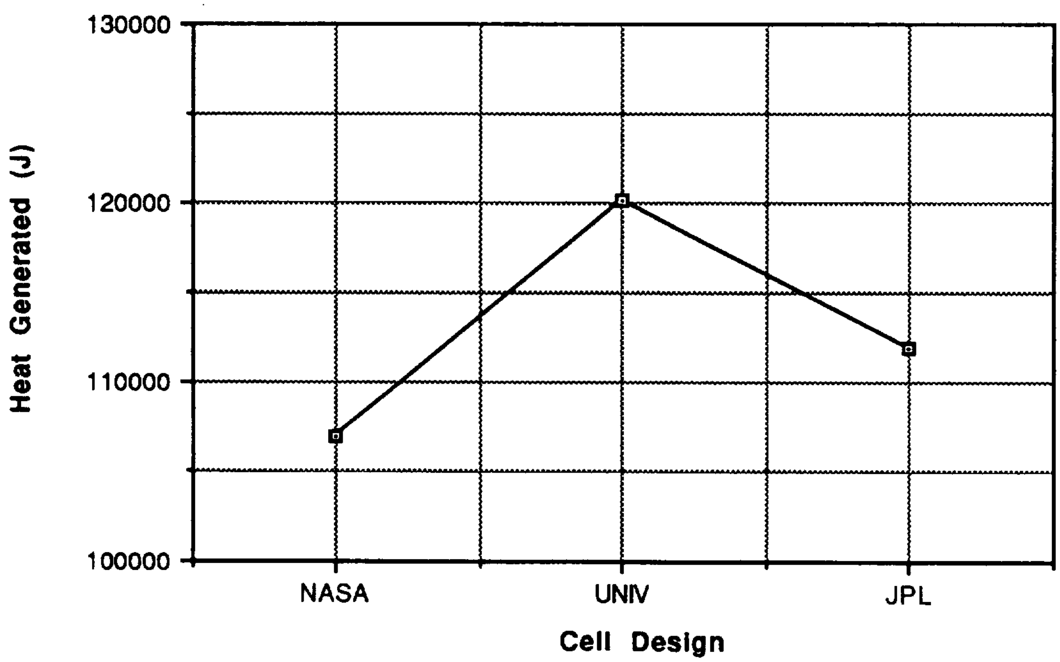


Figure 182

Effects of depolarizer type on capacity of D cells under 0.7Ω loads.

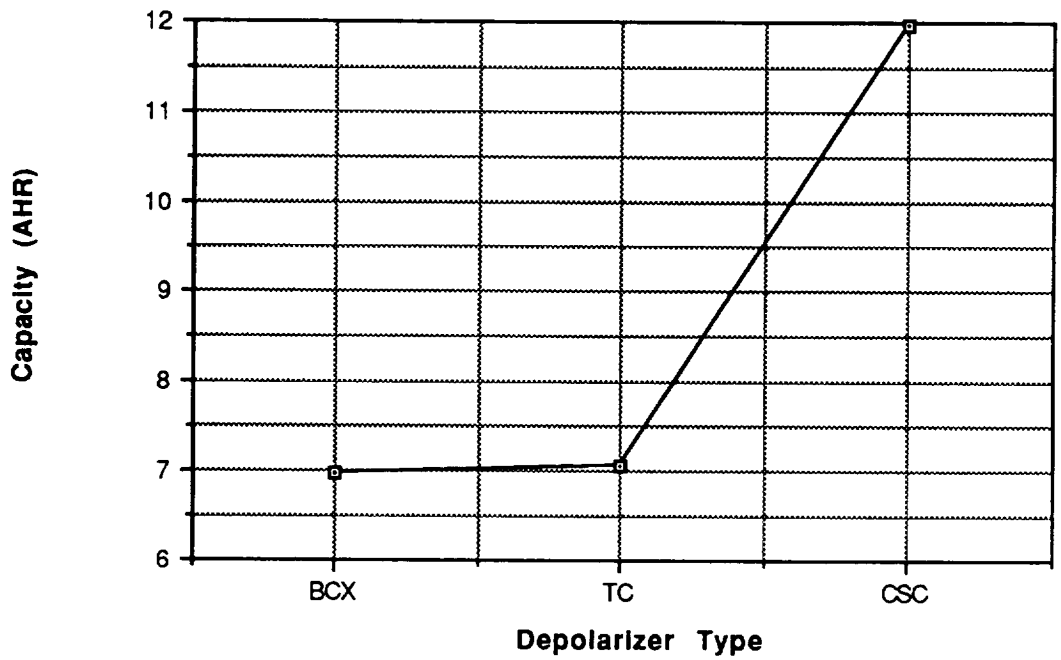


Figure 183

Effects of electrolyte concentration on capacity of D cells under 0.7Ω loads.

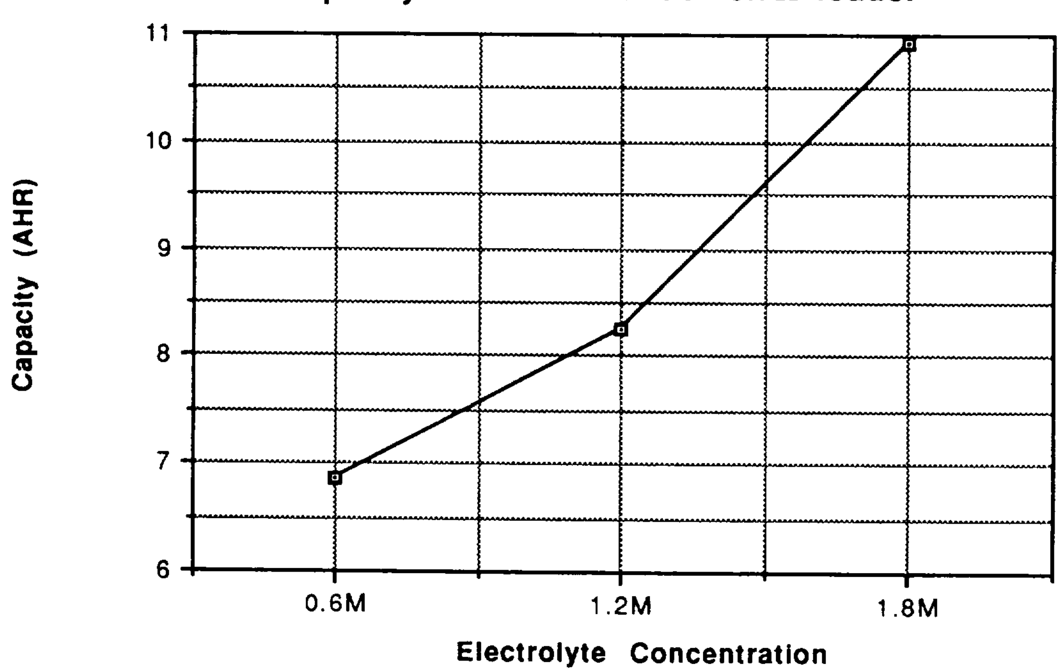


Figure 184

Effects of electrolyte type on capacity of D cells under 0.7Ω loads.

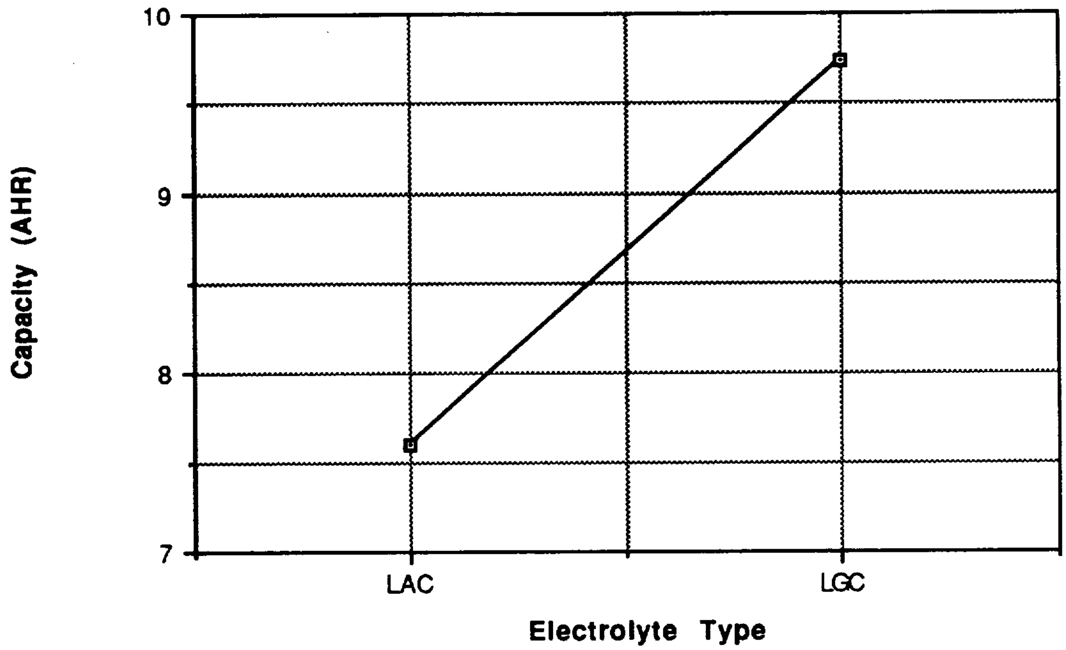
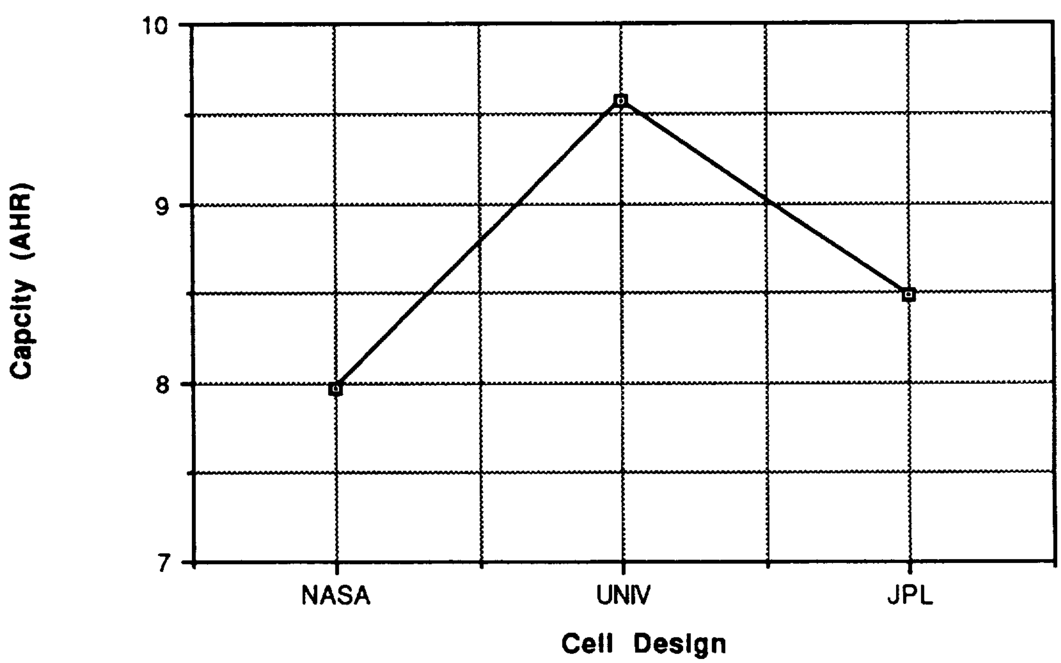


Figure 185

Effects of cell design on capacity of D cells under 0.7Ω loads.



(12736.8 J/Ah). The electrolyte type and the design type do not affect this safety attribute. Figures 186 - 189 illustrate the main effects of the four factors on the heat generated per Ah capacity under 0.7Ω loads.

6.5 SHORT CIRCUIT TESTING AT 0.325Ω

Short circuit testing at 0.325Ω was conducted on 18 D cells and the ANOVA reports for the three safety attributes are included in Appendix P. Figures 190 - 193 illustrate the main effects of the four factors on heat generated during this test. Outside noise contributes 46% to the variation in heat generated. The two factors contributing to the heat output are the depolarizer (22%) and the electrolyte concentration (30%). CSC depolarizer resulted in the highest heat output as did the high molarity electrolytes. The remaining two factors had no effect on heat dissipation.

The factors affecting the delivered capacity under 0.325Ω loads were the depolarizer type and the electrolyte concentration, contributing 23% and 32% to the variation in performance, respectively. The electrolyte type and the design have no effect on capacity at this rate. Figures 195 - 197 illustrate the effects of the four factors on capacity. Cells with CSC depolarizer delivered the highest capacities (10.95 Ah) compared to TC and BCX (7.69 Ah and 6.41 Ah respectively). The high molarity electrolyte cells delivered higher capacities than the lower molarity cells (see figure 195).

Figures 198 - 201 illustrate the main effects of the four factors on heat generated per Ah delivered capacity. The electrolyte type (figure 198) contributed 8.4% to the variation in this attribute and the cells with LGC electrolyte generated less heat per unit capacity than the cells with LAC electrolyte. The cell design had a somewhat larger effect than the electrolyte type (11.3%) and the JPL design had the lowest J/Ah ratio. The depolarizer contributed 15.6% to the variation in the J/Ah ratio and the CSC depolarizer is favored. The electrolyte concentration was the largest contributor of the four factors (32.7%) and the heat generated per Ah capacity decreases with increasing molarity.

SUMMARY OF SHORT CIRCUIT DATA

The short circuit characteristics of Li/oxyhalide D cells were determined at three rate where the area of concern was the heat generated upon short circuit. This safety attribute is important in assessing the relative effect of the four factors on possible damage to the immediate environment of the cell should a shorting condition occur. While the heat generated upon variable rate shorting conditions is easily determined, the analysis of the data is not so straight forward.

Figure 186

Effects of depolarizer type on heat generated per Ahr under 0.7Ω loads.

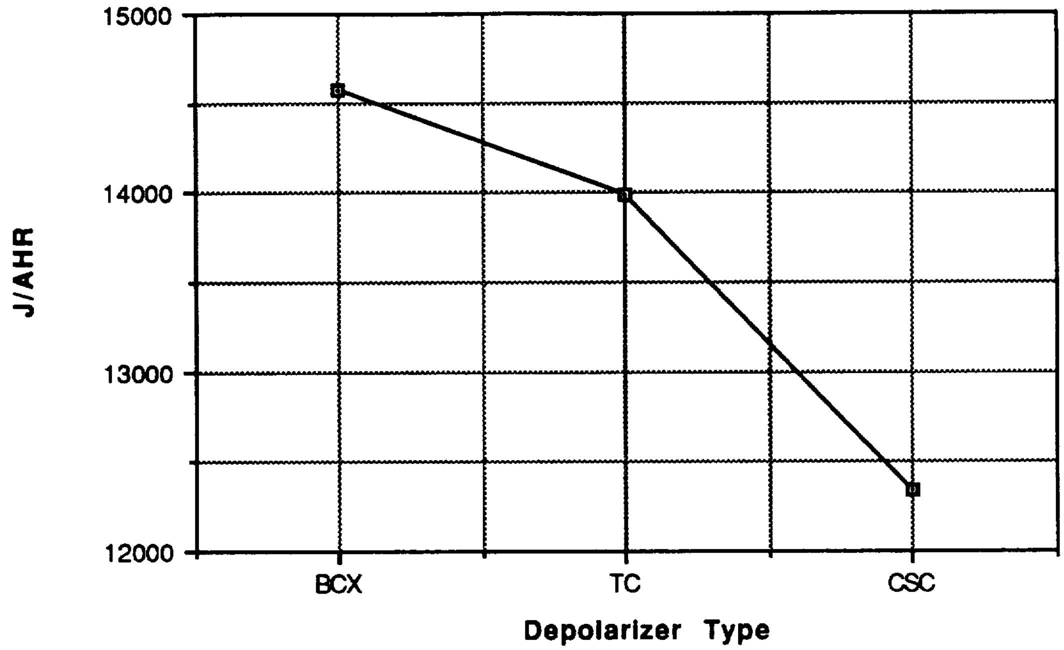


Figure 187

Effects of electrolyte concentration on heat generated per Ahr under 0.7Ω loads.

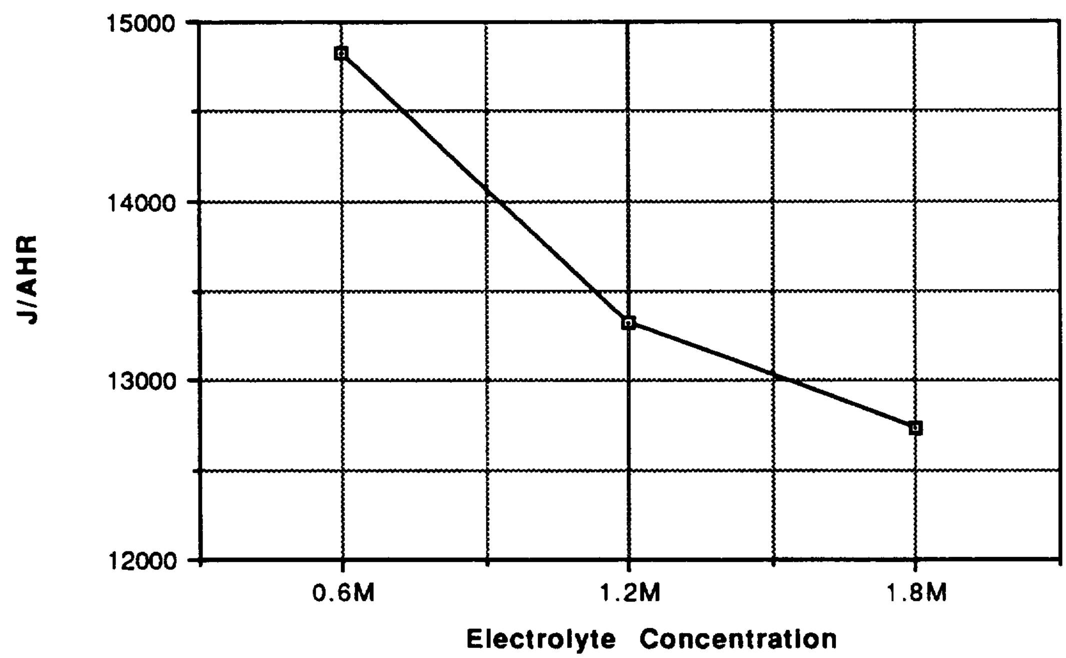


Figure 188

Effect of electrolyte type on heat generated per Ahr under 0.7Ω loads.

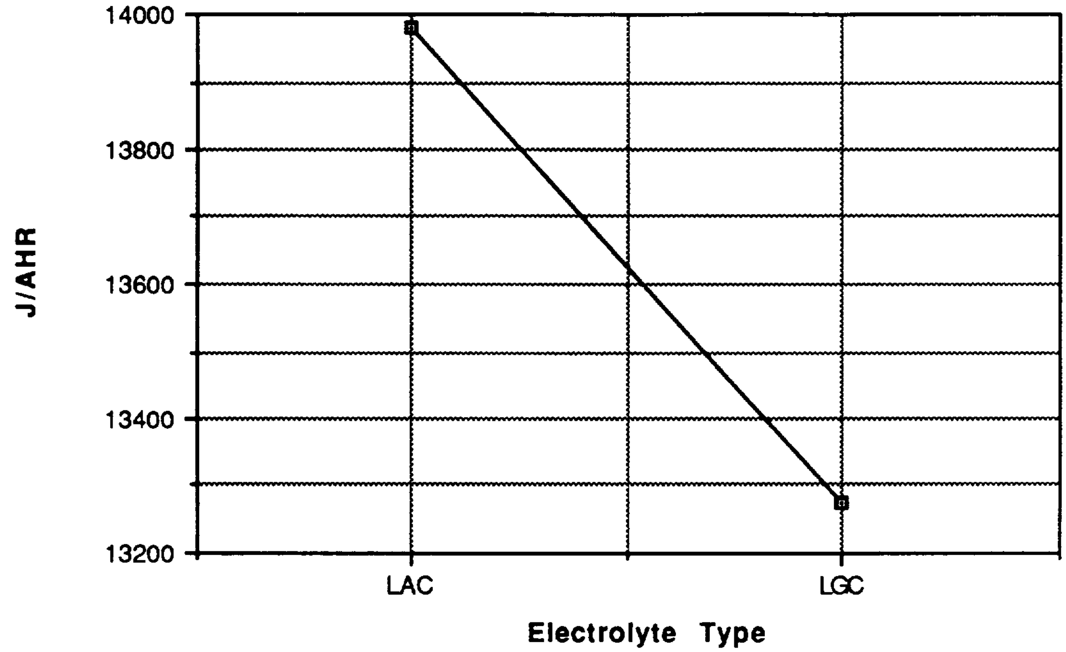


Figure 189

Effects of cell design on heat generated per Ahr under 0.7Ω loads.

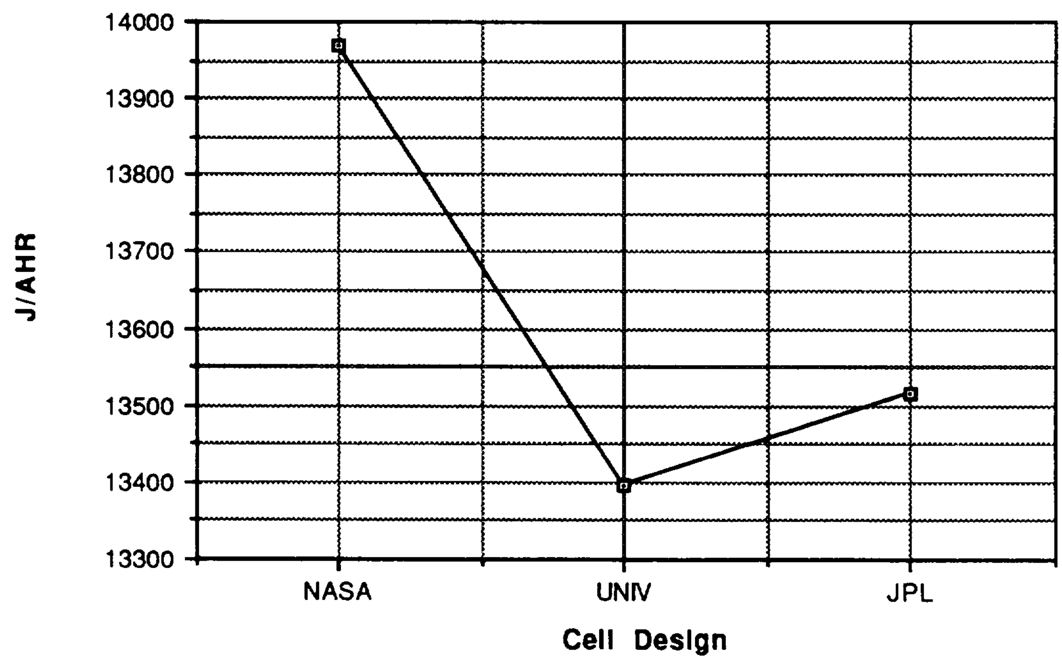


Figure 190

Effect of depolarizer type on heat generated in D cells under 0.325Ω loads.

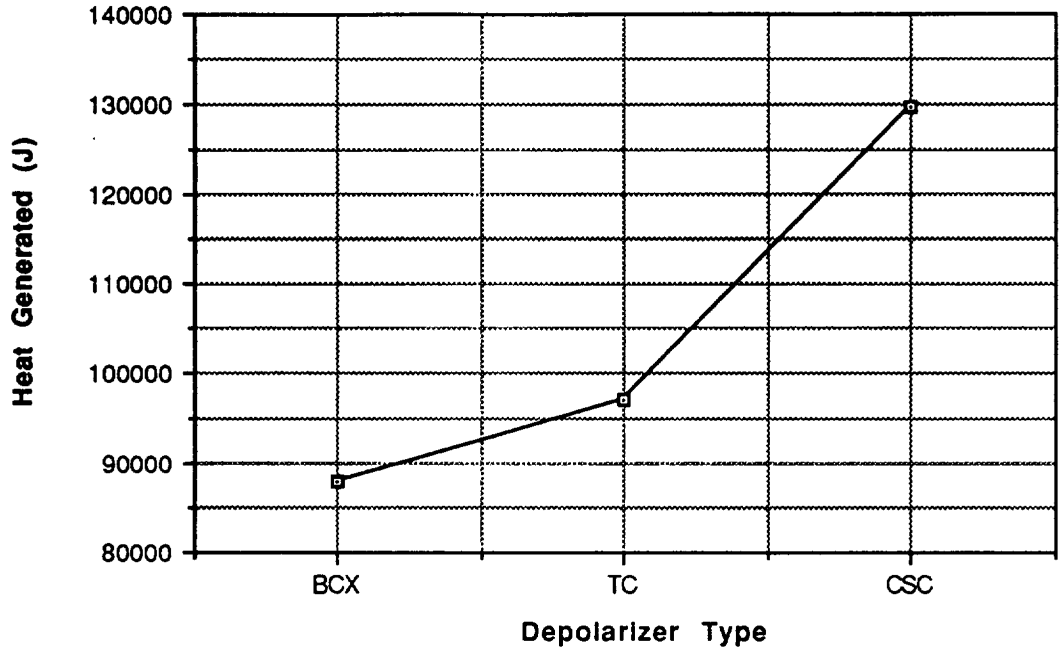


Figure 191

Effect of electrolyte concentration on heat generated in D cells under 0.325Ω loads.

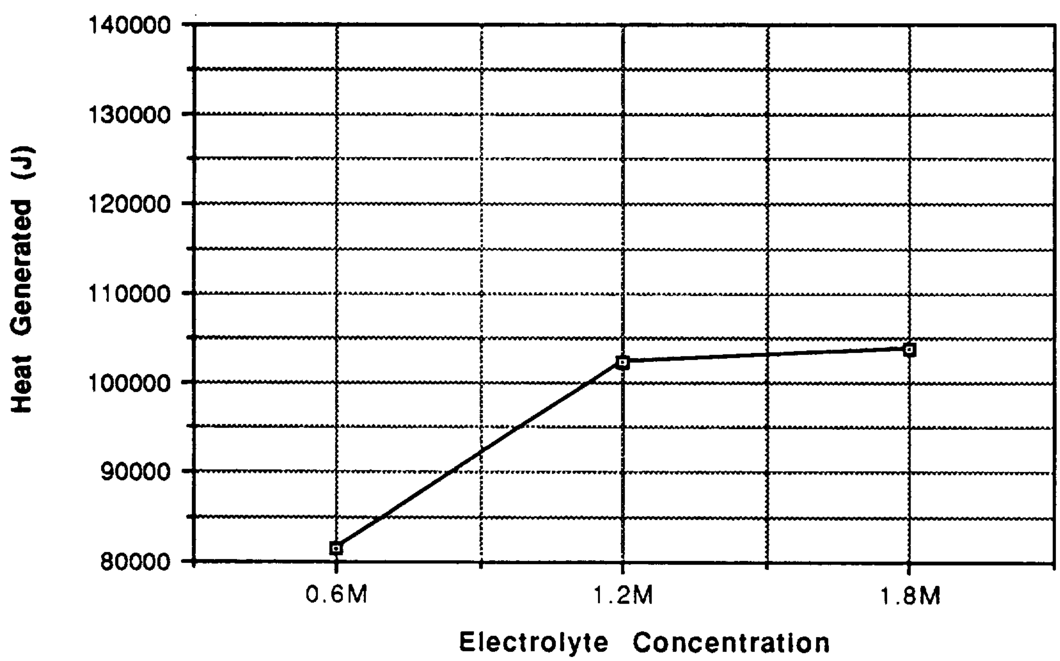


Figure 192

Effect of electrolyte type on heat generated in D cells under 0.325Ω loads.

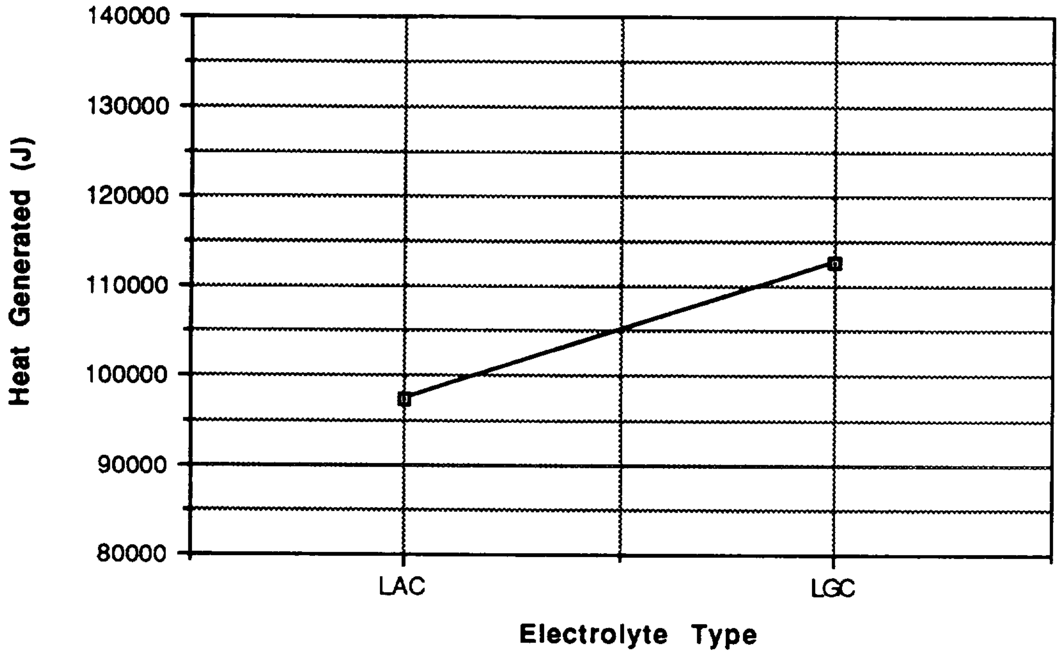


Figure 193

Effect of cell design on heat generated in D cells under 0.325Ω loads.

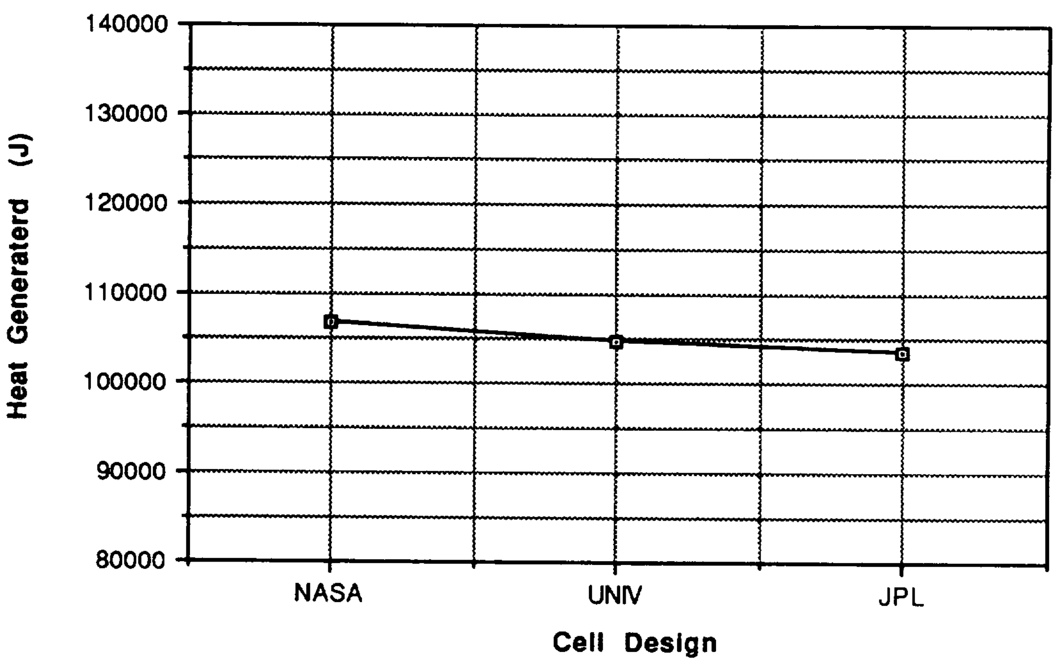


Figure 194

Effect of depolarizer type on capacity of D cells under 0.325Ω loads.

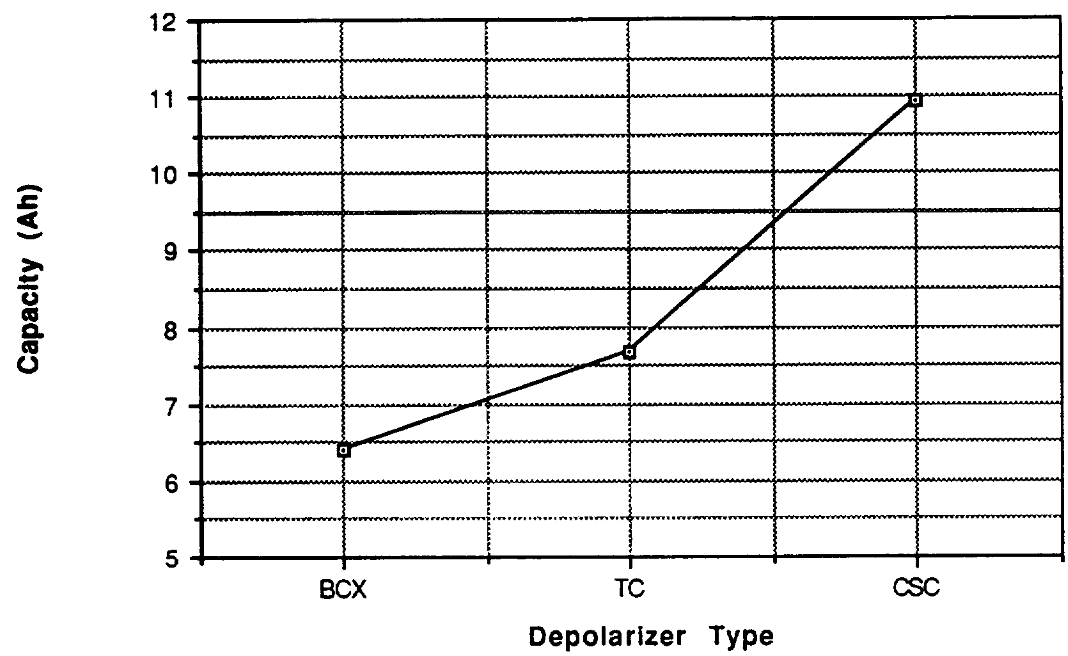


Figure 195

Effect of electrolyte concentration on capacity of D cells under 0.325Ω loads.

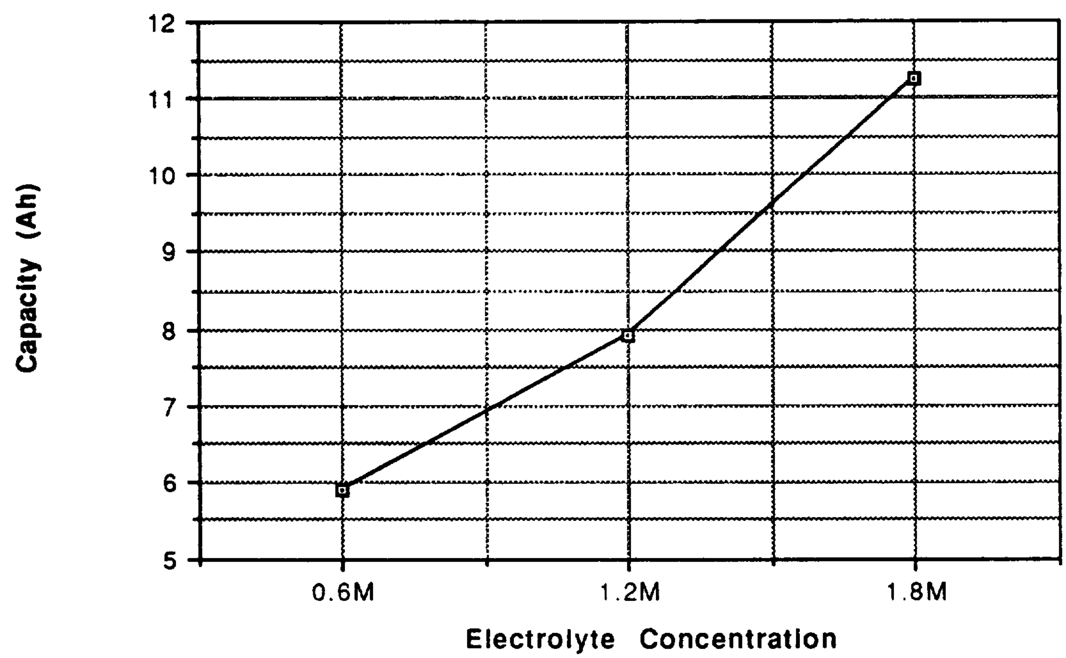


Figure 196

Effect of electrolyte type on capacity of D cells under 0.325Ω loads.

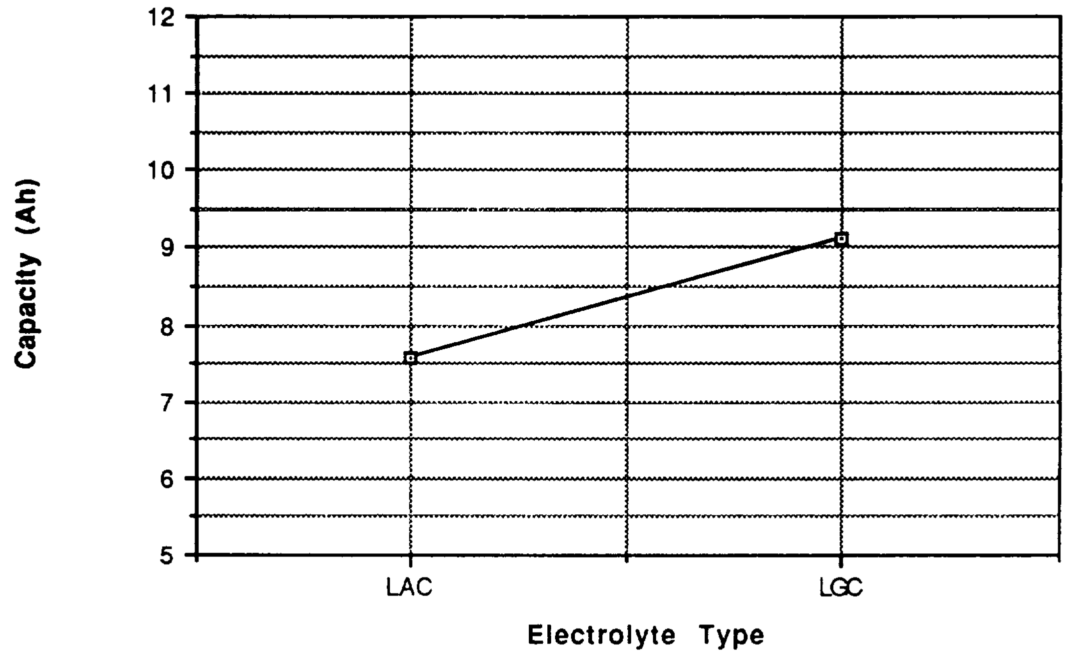


Figure 197

Effect of cell design on capacity of D cells under 0.325Ω loads.

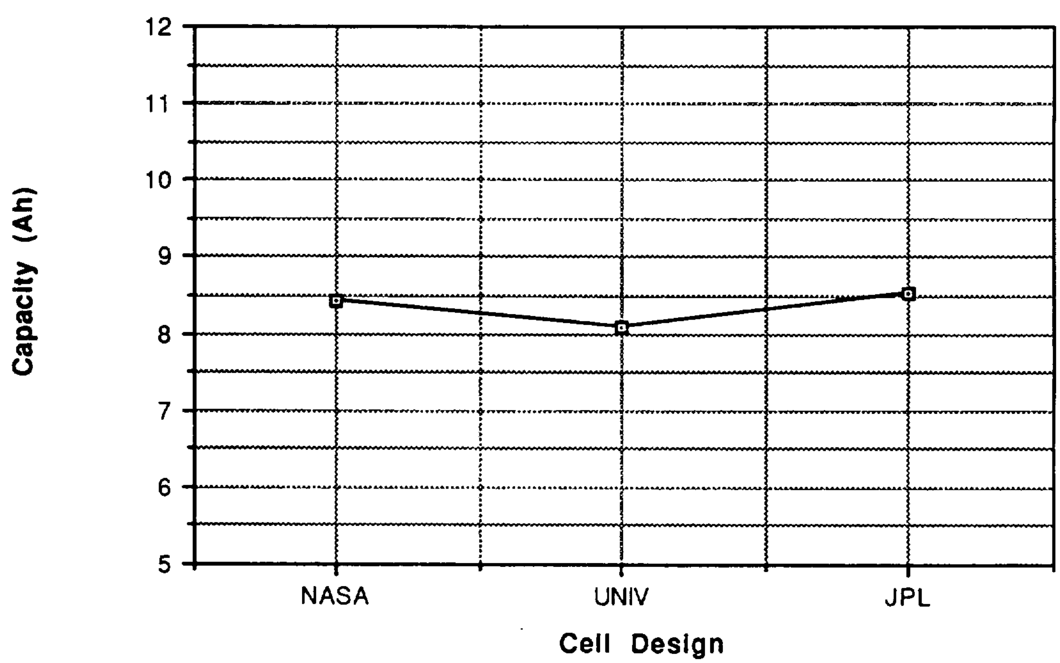


Figure 198

Effect of electrolyte type on heat generated per Ah under 0.325Ω loads.

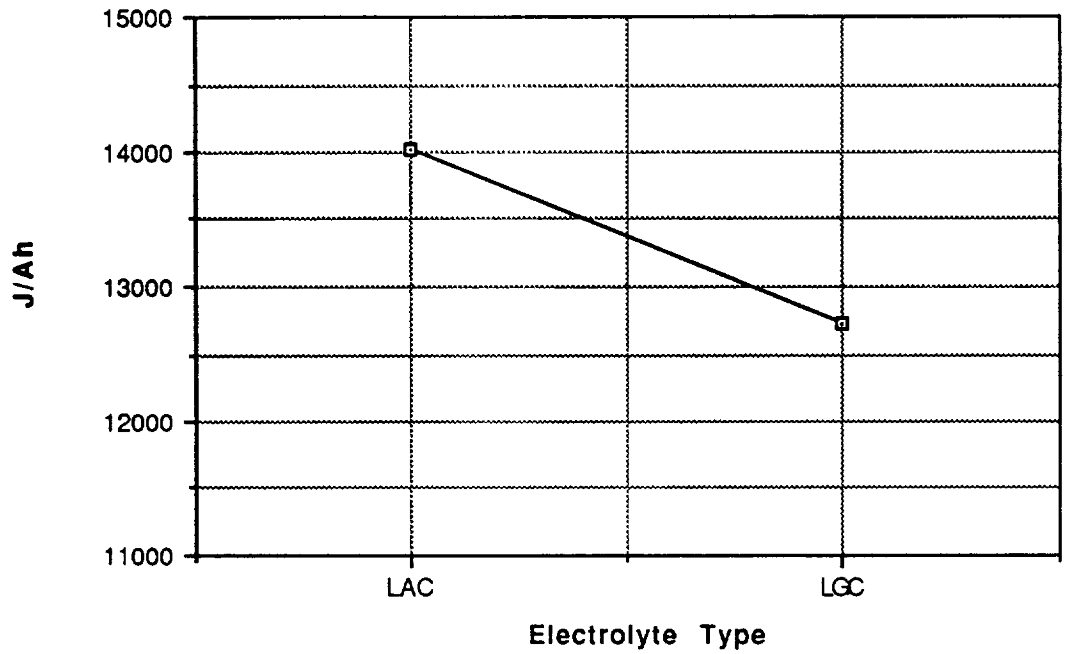


Figure 199

Effect of cell design on heat generated per Ah in D cells under 0.325Ω loads.

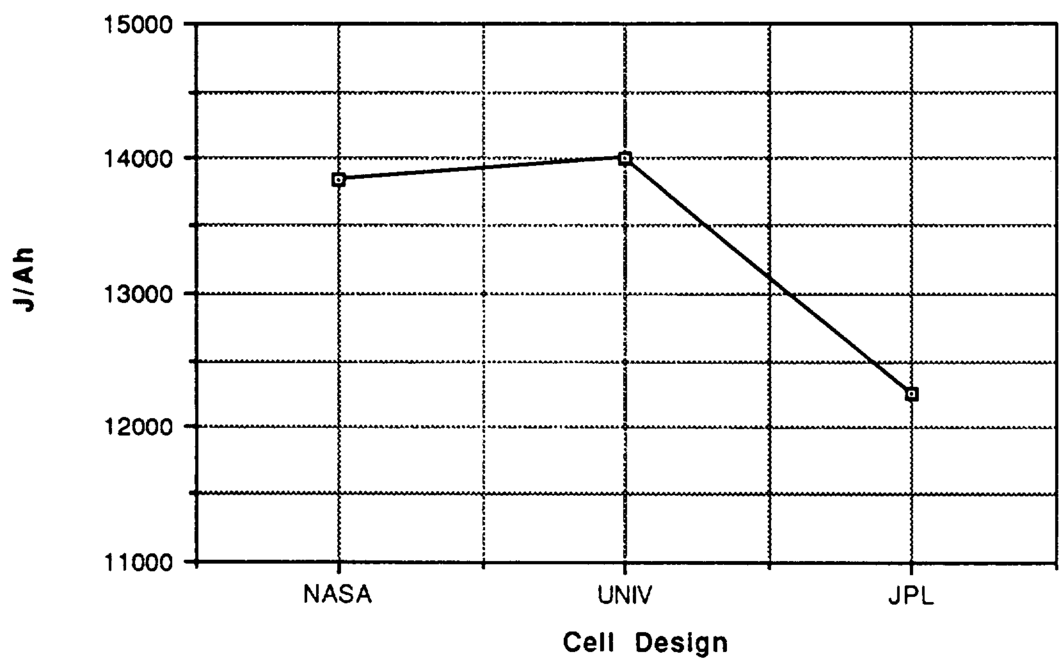


Figure 200

Effect of depolarizer type on heat generated per Ah in D cells under 0.325Ω loads.

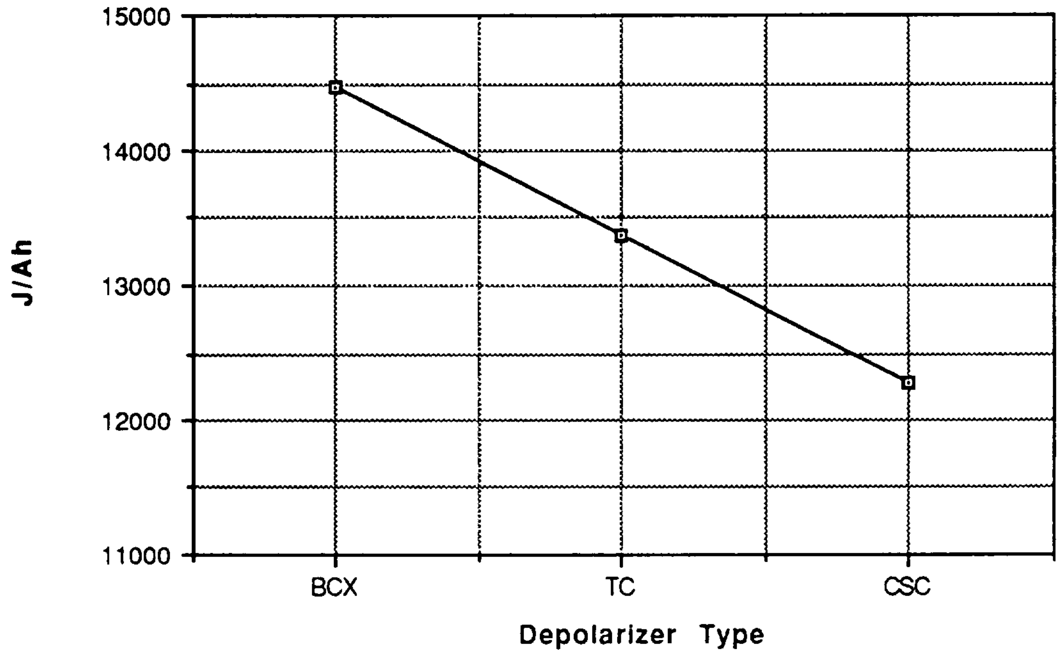
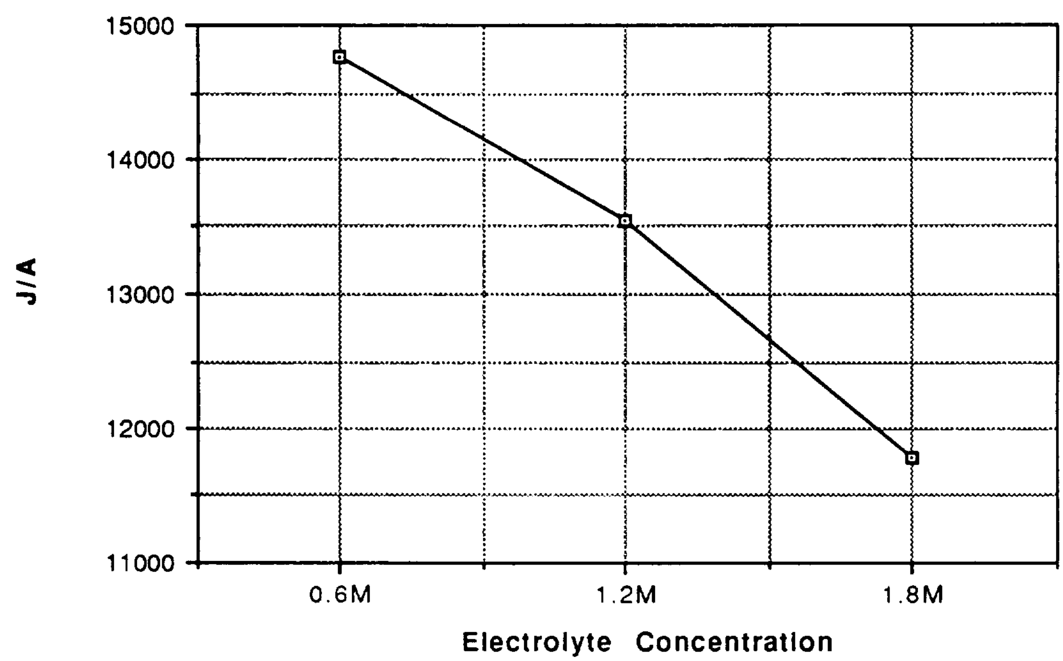


Figure 201

Effect of electrolyte concentration on heat generated per Ah in D cells under 0.325Ω loads.



Upon a first look at the heat generated during shorting conditions at any of the three rates tested, it would appear that the CSC depolarizer and high molarity electrolyte pose the greatest threat to components adjacent to the cell. Additionally it would appear that the UNIV design and the LGC electrolyte are culprits as well. However, on close examination of the data it was observed that the cell design and the electrolyte type had no real effect on heat dissipation, and cells with the UNIV configuration and LGC electrolyte actually ran longer than cells with the NASA and JPL configurations and LAC electrolyte. Cells with CSC depolarizer and high molarity electrolyte also ran longer than their counterparts. It therefore became necessary to examine the short circuit characteristics (ie., generated heat) from another viewpoint.

The total capacity and the heat generated per Ah are important areas to examine. Since the length of time that a cell discharges will have an effect on the amount of heat generated, it is important to look at the factors affecting capacity. In every case tested, the depolarizer has a large effect on capacity and cells with CSC depolarizer discharge longer than cells with either BCX or TC depolarizers. This is the reason for the higher heat outputs of cells configured with CSC depolarizer. The same case can be made for cells with higher molarity electrolyte. Cells with 1.8M electrolyte discharged longer than cells with 1.2M or 0.6M electrolyte, hence the higher heat output. Since the length of discharge affects the heat output, the heat generated per Ah delivered capacity was assessed. It was shown that when this safety attribute is examined it is clear that the CSC depolarizer, high molarity electrolyte , and to a lesser degree the LGC electrolyte may prove to be less threatening to the immediate surroundings of the spiral wound D cell.

7.0 SUMMARY

The main focus of this contract was to evaluate parametrically the effects of various design factors on performance and safety characteristics of spiral wound Li/oxyhalide D cells, and to determine the optimum configuration for future space applications. Primary to this effort was the concept of continued growth and improvement of manufacturing technology on the part of WGL in our efforts to meet the changing requirements of NASA.

Taguchi Methods of Experimental Design formed the basis of the work performed on this contract, and it involved state-of-the-art methodology for the collection and analysis of pertinent information. In this particular case a fractional factorial design utilizing 18 different configurations of D cells was employed to cover areas of electrical performance and safety characteristics under abusive conditions. Four design variables were studied in this effort, which included electrolyte type at

two levels, cell design type, depolarizer type, and electrolyte type, each at three levels. The electrolyte types studied were lithium aluminum chloride (LAC) and lithium gallium chloride (LGC). The current WGL UNIV D cell design was compared to the NASA D cell and the JPL D cell. Three common oxyhalide depolarizers studied were BCX (BrCl in thionyl chloride), TC (thionyl chloride) and CSC (Cl_2 in sulfuryl chloride). The range of electrolyte concentrations studied included 0.6M, 1.2M and 1.8M electrolyte salt.

Five hundred and forty D cells were constructed in a laboratory setting for prototype purposes. While the initial intent of this contract was to machine wind all cell designs, the NASA cell proved to be impossible to machine wind without significantly altering the original cell design and affecting cell performance. Therefore all NASA cells were hand wound for the purpose of this contract. Hollingsworth and Vose separator material was utilized in all cells, and lot commonality of active materials was maintained, with the exception of the NASA cells. All cells were constructed with 0.093" headers. All cells were manufactured to be temperature tolerant to 149°C. One hundred and eight D cells were manufactured as extras to replace those with manufacturing defects or those involved with testing malfunctioning. At the completion of the testing there were 89 cells remaining, which were delivered to Johnson Space Center.

Acceptance testing was patterned after NASA document EP5-83-025 Rev. E for weights, open circuit voltage, and load voltage. These tests were conducted merely to establish values of the three attributes for the eighteen configurations, and not as pass/fail criteria. In addition to these three tests, the cells were exposed to 160°F prior to finishing to check for defects in the glass to metal seal area. There were no rejects as a result of this test. Acceptance data were delivered to Johnson Space Center along with the 89 D cells.

Electrical performance characteristics were evaluated for total capacity, start-up, rate capability, running voltage, capacity retention, microcalorimetry, and temperature tolerance. Capacity and rate capability were evaluated for fresh cells at 1A and 3A and both 25°C and -25°C. Start up characteristics were also evaluated at each of these test conditions, and voltage was measured at 1, 5, and 60 seconds. Running voltage was determined at each of these conditions at 50% DOD. After a one year storage period at room temperature, the 1A and 3A discharge tests were repeated at 25°C, and the capacity, start-up, rate capability and shelf-life characteristics were evaluated.

Microcalorimetry measurements were obtained four times over the course of one year at room temperature and OCV. The effects of the four factors on self-discharge current were established for

each iterative measurement.

Temperature tolerance information was obtained for the eighteen configurations by exposing cells to temperatures of 139°C, 149°C, and 159°C and assessing the amount of change in cell containment as a result. It should be noted that this test does not lend itself to Taguchi analysis for two reasons. First of all the output of this type of experiment is not accurately quantified, which adds error to the experiment. Second, the temperature tolerance is determined by the establishment and maintaining of the internal void volume, which can be adjusted for any of the configurations once optimized. The factors studied in the experiment are known to have no effect on temperature tolerance.

The safety characteristics of the various configurations were evaluated under abusive conditions which included forced-over-discharge (FOD) at two rates, and variable rate short circuit. FOD was conducted at constant currents of 1A and 3A both with and without bypass diodes. The resulting physical change in cell containment was evaluated based on a rating system of 1 - 6 where 1 = no change and 6 = cell rupture.

Short circuit information was obtained under three resistive loads which resulted in currents of 1.5 - 8.5A. The heat output of each configuration was determined by immersing the cells in a heat sinking liquid of known heat capacity which was in a thermally insulated container (also of known heat capacity) and measuring the change in temperature of the liquid during the discharge test. The amount of heat dissipated from the cell was then calculated.

8.0 RECOMMENDATIONS

Advancement in cell technology and manufacturing processes at WGL have resulted in improved manufacturability as well as product consistency. These changes in processing methods have included common electrode configurations for various cell sizes, improved cathode manufacturing processes, and standardized anode materials, all of which have aided in the conversion to machine wound assemblies. These changes in technology have lead to a more universal approach to cell design and manufacturing, and hence the UNIV (universal) cell design. This cell design represents our efforts to produce a readily manufactured spiral wound cell which allows for consistency of product and performance, and allows mainstream manufacturing, rather than having a unique design which requires diversification of manufacturing procedures. From this perspective, the UNIV cell design is strongly recommended as it is manufacturable, consistent, and meets a wide range of applications.

Based on the electrical performance of D cells at rates of 1A and 3A, the one factor that consistently delivers high performance is

the LGC electrolyte salt. LGC offers maximum capacity along with being a good voltage delay alleviator, a combination which rarely exists. LGC electrolyte is especially effective in retaining capacity and providing quick start up of cells after long term storage at both moderate and high rates. LGC has a small effect on microcalorimetry of aged cells, and results in decreased self-discharge rates.

A good case can be made for BCX depolarizer. BCX offers good start up capabilities and performs well under moderate rates. If power is an issue, the CSC depolarizer is more effective at the higher rates.

The cell design is not a strong factor in determining electrical performance under the conditions of this contract. The NASA and UNIV designs have lower self-discharge rates than the JPL design as determined by microcalorimetry. The JPL cells deliver slightly higher fresh capacities than the UNIV and NASA cells at high rates, but does not show an advantage in capacity retention.

The electrolyte concentration affects two aspects of cell performance: start up and rate capability. Low molarity electrolyte offers some improvement in alleviating voltage delay, while high molarity electrolyte provides better capacity at high rates.

None of the factors affect temperature tolerance, and this performance attribute can be adjusted for whatever cell configuration is chosen for optimum performance.

Under FOD conditions, outside noises contribute significantly to the experiment. However, the JPL design and the BCX depolarizer proved to be the most benign.

The depolarizer and the electrolyte concentration had the largest effect on heat output under variable rate short circuit. In terms of total heat output, high molarity electrolyte and CSC depolarizer result in higher amounts of heat generated. However, on the basis of heat output per Ah, these two factors have the opposite effect.

The effects of the four factors in this experiment on electrical performance and safety attributes have been characterized and summarized. While no one combination of factors is superior in all aspects of cell performance, some factors are strong contributors in several of the attributes characterized. The optimum cell design therefore depends on the performance and/or safety characteristic that is most important to the application of the cell. The characteristics of rate capability, shelf-life, voltage delay, total capacity, physical integrity, and heat output have all been assessed. It is ultimately a decision of the end

user as to which of these attributes are of utmost importance.

9.0 REFERENCES

1. T.B. Barker, Engineering Quality by Design, Marcel Dekker, Inc., 1990.

2. B. Bragg - private conversation

10.0 APPENDICES

A. NASA JSC DOC. EP5-83-025 Rev. E

B. ANOVA reports for fresh 1A room temperature discharge.

C. ANOVA reports for fresh 1A, -25°C discharge.

D. ANOVA reports for fresh 3A room temperature discharge.

E. ANOVA reports for fresh 3A, -25°C discharge.

F. ANOVA reports for 1A room temperature discharge after 1 year.

G. ANOVA reports for 3A room temperature discharge after 1 year.

H. ANOVA reports for microcalorimetry data.

I. Short circuit test procedure from Hazard Definition study.

J. Reliability report #92-066; 1A FOD without bypass diodes.

K. ANOVA report for 1A FOD without bypass diodes.

L. ANOVA report for 3A FOD without bypass diodes.

M. Reliability report #92-080; 3A FOD without bypass diodes.

N. ANOVA reports for 2Ω short circuit testing.

O. ANOVA reports for 0.7Ω short circuit testing.

P. ANOVA reports for 0.325Ω short circuit testing.

APPENDIX A

NASA JSC DOC. EP5-83-025 REV. E

PROJECT DOCUMENT COVER SHEET

SPECIFICATION FOR
ACCEPTANCE AND LOT CERTIFICATION TESTING
OF LITHIUM-BROMINE COMPLEX CELLS AND BATTERIES
FOR DELIVERY TO
NASA, JOHNSON SPACE CENTER

REPORT NUMBER	DATE
EP5-83-025	9-8-83

PREPARED BY:	J. B. Trout/NSI J.B. Trout – 8/3/83
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NO. OF PAGES ______

REVISIONS					
DATE	PREPARED BY	APPROVALS			CHG. LETTER
		BRANCH	DIVISION	~~PROGRAM~~ SR+QA OFFICE	
3/14/84	J. B. Trout JBT 3/14/84	BJB 3-16-84 DAW 3-16-84 WEB 3/19/84	HOP 3/19/84	D Dittmar 3/31/84 MHE for G Perez 4/?/84	A
11/15/88	J. B. Trout JBT 11/21/88	GEK, for BJB 12/20/88 TG	[illegible] 1/11/89	D Dittmar 2/2/89 JBS 1/31/89	B
1/31/91	E.C. Darcy ECD 1/31/91 BJ Bragg 2/1/91	BEW 2/01/91 [illegible] 2/1/91	[illegible] 2/5/91	C. J. Katiskas 2/11/91 D Dittmar 2/19/91	C
1/29/92	E.C. Darcy E.C.D. 1/28/92	BJBragg 1/29/92 [illegible] 1/29/92	—	C. J. Katiskas 2/?/92	D
8/28/92	E.C. Darcy ECD 8/28/92	[illegible] 9/2/92	N/A	C. J. Katiskas 9/8/92	E

REPORT NUMBER

JSC Form 151A (Jul 69)

SPECIFICATION FOR ACCEPTANCE TESTING AND LOT CERTIFICATION TESTING OF Li-BCX CELLS AND BATTERIES FOR DELIVERY TO NASA JOHNSON SPACE CENTER

1.0 SCOPE

The cells and batteries covered herein are those described in Appendix A hereto. Cells and batteries shall be manufactured according to the provisions of Electrochem Industries Quality Plan 17096, Rev. D.

2.0 ACCEPTANCE TESTS

The following tests shall be performed prior to the tests of 3.0 on every cell/battery submitted for delivery to NASA. Failure on any test or measurement for which pass/fail criteria are given shall result in rejection of the cell/battery which is nonconforming.

2.1 160°F EXPOSURE

2.1.1 After cell assembly has reached the stage where the cells have been filled and sealed, but before addition of any further cell parts, all cells shall be placed in an appropriate heating chamber or oven in which the cell temperatures shall be brought to 160°F ± 10°F as measured by a thermocouple placed on the cylindrical surface of a cell. More than one thermocouple should be used if doubt exists as to uniformity of heating conditions in the chamber. When the cells reach the above temperature control limits, they shall be kept there for a period of 2 ± 0.1 hours. Cells shall then be permitted to cool to within 5°F ambient room temperature before the tests of 2.2-2.7 are performed. After cooling, examine each cell for any permanent deformation and for any damage to the glass hermetic seal. Reject deformed cells or cells with cracked or broken seals, or cells indicating any evidence of leakage.

2.1.2 In the instance of multi-cell batteries, this test shall be performed on the cells from which the batteries are to be made.

2.1.3 After completion of this test, all cells (including those to be assembled into batteries) shall have their assembly completed and shall then meet the following requirements by test or measurement.

2.2 SERIALIZATION

Each cell shall have an identifying number placed on its cylindrical surface. The number, along with date/lot code legend, shall then be the unique identifying serial number of each cell.

2.3 OPEN CIRCUIT VOLTAGE

Open circuit voltage (OCV) shall be 3.85 volts, minimum. Record OCV versus serial number of all cells in the lot.

2.4 LOAD TEST

Load test each cell using the applicable load listed in Appendix A for 90 ± 10 seconds. At the end of this test, cell voltages shall be at least 3.50 volts on load.

2.4.1 All cells yielding at least 3.50 volts have passed the test.

2.4.2 Any cell yielding less than 3.40 volts is a failure and shall be rejected.

2.4.3 Any cell yielding a voltage less than 3.50 volts, but not less than 3.40 volts, shall be subjected to retest after a minimum wait of 3 hours. If the voltage yielded on retest is still less than 3.50 volts, the cell is a failure. No further retest is permitted.

2.4.4 Record time to 3.50 volts and load voltage at 90 seconds versus serial numbers.

2.5 DIMENSIONAL CHECK

Diameter and length shall be within the tolerances shown on the drawing listed in Appendix A. The length dimension shall be measured along the central axis of the cell, including solder tabs if present, *but excluding shrink wrap ruffles*. Record length and diameter by cell serial number.

2.6 WEIGHT CHECK

The weight of each cell shall be within the tolerances shown in Appendix A. Record weight by cell serial number.

2.7 CELL X-RAYING

2.7.1 After final cell assembly, each cell shall be X-rayed to examine its as-built internal configuration. Two views shall be taken. One view shall be perpendicular to the cylindrical side of the cell can and include the entire height of the cell. The other view shall be the same, except the cell shall be rotated about its axis 90°. It shall be permissible to make additional views of any cell in which there appears to be a defect not clearly depicted in the first two views. At least one view shall be capable of detecting any positive pin defects. Any evidence of pin corrosion shall be reported.

2.7.2 X-ray inspection shall be performed per Electrochem Industries Quality Control Instruction and no sooner than one calender week after cell closure.

3.0. LOT CERTIFICATION

The following tests shall be passed successfully prior to acceptance by the Government and shall be performed on lot samples selected randomly in the quantities given in 3.2. Failure on any test for which pass/fail criteria are given shall result in lot rejection. Cells shall be completely assembled for this test, except as noted. Randomness of sample selection shall be assured by use of standard statistical methods.

3.1 CERTIFICATION LOT DEFINITION

For purposes of lot sampling and without regard to the manufacturer's system for date/lot coding of individual cells, the Certification Lot shall be all those cells which have been consecutively made within four consecutive calendar days using a single batch of electrolyte mix for filling. Additionally, the cells shall be made using one batch only of lithium anode material, cathode mix and separator material.

3.2 SAMPLE SIZES

The sample sizes for the various tests requiring unused samples are given below:

Test Paragraph	Test Title	Percent of Certification Lot in Sample*
3.3	Capacity Discharge	9%, but not less than *6 cells*
3.4	High Temp.Exposure	*3%*, but not less than *1 cell*
3.8	Short Circuit	4%, but not less than 1 cell
3.9	300°F Exposure	*2 cells/lot*
3.10	Vibration	4 cells/lot

* Percent calculations shall be rounded upward to the next integer.

3.3 CAPACITY DISCHARGE

The sample cells each shall be discharged through a constant resistance having the applicable value shown in Appendix A to a test end voltage of 2.0 volts, while at a temperature of 70°F +/- 10°F at ambient atmospheric pressure. The ampere-hours of capacity given by each cell shall be calculated, and the arithmetic average of the ampere-hour values determined. The average ampere-hours shall not be less than the minimum average value specified in Appendix A. All discharged samples shall subsequently be used in the Fuse Check Test of 3.6, *200 F Exposure of 3.4, and Vibration Test of 3.10 according to Fig.1*. All cell capacities shall be reported to NASA.

3.4 HIGH TEMPERATURE EXPOSURE

The sample for this test will consist of a 50-50 mix of BOL and EOL cells as shown in Fig.1. Cells will come from about one-third of the sample used in the Capacity Discharge of 3.3 (but no less than 1) and 3% of the BOL certification lot (but no less than 1). The sample cells shall be placed in an appropriate heating chamber or oven without touching each other. They shall be brought to a temperature of 200°F ± 10°F as measured by a thermocouple placed on the cylindrical surface of a cell. More than one thermocouple should be used if doubt exists as to uniformity of heating conditions in the chamber. When the cells reach the above control limits, they shall be kept there for 2.0 ± 0.1 hours. They shall them be allowed to cool to within 5°F of ambient room temperature before examination. They shall then be visually examined and shall exhibit no venting or leakage, nor gross damage of the shrink wrap and terminated assembly. This test shall be run with finished cells and subsequent examination of the headers shall be performed with the cell headers exposed.

3.5 HIGH RATE DISCHARGE

Upon passing the High Temperature Exposure Test of 3.4 *and the vibration test of 3.10*, the sample cells from those tests shall each be discharged through the resistance specified in Appendix A to a test end voltage of 2.0 volts, while at a temperature of 70°F ± 10°F at ambient atmospheric pressure. The ampere-hours of capacity given by each cell shall be calculated and reported to NASA. No pass/fail criterion applies to this test.

3.6 FUSE CHECK TEST

All cells used in the Capacity Discharge Test of 3.3. which are not diverted to Vibration Test of 3.10 and the High Temperature Exposure Test of 3.4, but no less than 3 cells shall be subjected to the Fuse Check Test, below.

3.6.1 Remove the terminal cap and hot melt glue under the cap, exposing components under the cap, in a manner which results in no damage to the fuse. Verify that all components are present between the cell header and the terminal cap as specified in the drawing cited in the purchase order or contract. If any part is missing, the lot shall be rejected *or reterminated followed by a repeat of 3.6.*

3.6.2 Using a constant current power supply, pass an amount of current equal to twice the fuse rating through the fuse. The fuse shall blow within 15 seconds *(for the fast blow version) or 60 seconds (for the slow blow version)* of application of current. The power supply connections should be made at the positive terminal post and the terminal cap, thus including the fuse in a circuit external to the cell. Failure of a fuse to blow as above shall result in failure of the lot, *or its retermination followed by a repeat of 3.6.*

3.6.3 *All but one of these* cells shall then be used in performing the Overdischarge Tests of 3.7. *That one cell will be used in the 300 F Oven Test of 3.9.*

3.7 OVERDISCHARGE CAPABILITY TESTS

3.7.1 *Store the cells* at room ambient temperature for 3 ± 1 weeks. After the storage period, place the cells on overdischarge according to the table below. Use a constant current power supply in series with each cell as the driving force for overdischarge. Install a shunt diode on each cell as specified in the table below. For the 160°F tests, the cells may be overdischarged in series up to 15 cells at one time. *Current is to be maintained within the stated limits provided that no more than 3.0 volts per cell be applied to the series. Should the maximum power supply voltage be reached, voltage will be maintained at the maximum level and current will be allowed to drop. The duration of the test remains at 16 hours (i.e. for 15 cells in series, power supply would be set to supply the desired current up to a maximum supply voltage of 45 volts).*

CELL SIZE AND DIODE NUMBER	NUMBER OF CELLS PER TEST	CONSTANT OVERDISCHARGE CURRENT (amperes)	OVERDISCHARGE DURATION (hours)	TEST TEMP (°F)
AA IN5817 IN5818 IN5819	1	2 ± 0.1	Until a minimum of two hours has elapsed at a negative cell voltage.	Room Temp
	Rest of first 6% but at least 1	0.1 ± 0.01	16 + 0.5/-0 then 16 additional hours with diodes removed.	160°F
C IN5817 IN5818 IN5819 IN5820 IN5821 IN5822	1	3 ± 0.1	Until a minimum of two hours has elapsed at a negative cell voltage	Room Temp
	Rest of first 6% but at least 1	0.5 ± 0.01	16 +0.5/-0 then 16 additional hours with diodes removed.	160°F
D IN5820 IN5821 IN5822 IN5823 IN5824 IN5825	1	3 ± 0.1	Until a minimum of two hours has elapsed at a negative cell voltage.	Room Temp
	Rest of first 6% but at least 1	1.0 ± 0.01	16 +0.5/-0 then 16 additional hours with diodes removed.	160°F
DD IN5823 IN5824 IN5825 MBRD660CT	1	4.7 ± 0.1	Until a minimum of two hours has elapsed at a negative cell voltage.	Room Temp
	Rest of first 6% but at least 1	3.0 ± 0.1	16 +0.5/-0 then 16 additional hours with diodes removed.	160°F

3.7.2 If any of the cells tested at room temperature or at 160°F leaks, vents or explodes during the overdisharge period while protected with a shunt diode, the manufacturer shall perform a failure analysis. If a faulty diode is credited with causing the event, the test shall be repeated with a new cell, from the same lot, and new diodes, otherwise, the lot shall be rejected. The 16-hour tests at 160°F without shunt diode protection are for information and have no pass/fail criteria. The testing with shunt diodes must be passed with no leaks, vents, or explosions, both for the high rate, 2 hour tests at room temperature and for the 16 hour tests at 160°F.

3.8 SHORT CIRCUIT TESTS

Sample cells selected for this test per 3.2 (4% of lot) shall have their integral fuses bypassed and be short-circuit tested in a suitable, protective chamber as follows.

3.8.1 Mount the cell by fastening it down lengthwise in a piece of angle iron of the size given below:

Cell Size	Angle Iron Size
AA	1" x 1" x 1/8" x 12"
C	1-1/2" x 1-1/2" x 3/16" x 12"
D & DD	2" x 2" x 1/4" x 12"

3.8.2 Condition the cell to a temperature of 75°F ± 10°F, measured on the cylindrical surface of the case. Subject the cell to a resistance load of approximately 50 milliohms or as indicated in Appendix A. The resistance shall be the minimum value which will not fuse internal plate tab connections of the particular cell size being tested. If the plate tabs fuse open in the course of this test, it must be repeated at a higher resistance with additional samples. Record cell voltage, current and temperature from the time 5 seconds before switching on the load until test end (given below). The record of at least the first 5 minutes should be on a strip chart, or other permanent, high resolution record.

3.8.3 Terminate load when cell temperature ceases to rise for at least 5 minutes.

3.8.4 After the cell temperatures have declined to 85°F or below, open the chamber and examine the cells for evidence of venting, leaking, bulging or other non-nominal condition. The cells shall not vent or leak on this test unless the cell temperature exceeds 300°F on the cell case during the course of testing.

3.9 300°F EXPOSURE TEST

Two sample cells shall be in the same configuration as cells subjected to the 160°F exposure test of 2.1. *One cell shall come from the 160 F ExposureTest of 2.1 and the other from the Fuse Check of 3.6.* Place the cells in a thermal chamber and raise the chamber temperature to 300°F ± 5°F at a rate not to exceed 5°F per minute. When 300°F ± 5°F is reached, as determined by a thermocouple on the test cells, maintain temperature for a minimum of fifteen (15) minutes. Then allow the temperature to decrease back to 85°F or less. Examine the cells visually, and examine the glass-to-metal hermetic glass seals under at least seven power (7x) magnification. The cells may exhibit permanent bulging, but there shall be no evidence of electrolyte leakage anywhere on the cells, especially at the glass seal and at the welds. Evidence of electrolyte leakage shall result in rejection of the lot.

3.10 VIBRATION

3.10.1 Subject the sample cells to random vibration according to the following spectrum for 15 minutes in each of 3 mutually perpendicular axes:

Frequency (Hz)	Level
20 to 80	+3 db/octave
80 to 350	0.10 g^2/Hz
350 to 2000	-3 db/octave

3.10.2 Continuously record open circuit voltage of each cell for a time period beginning 5 seconds (or more) before starting vibration and ending 30 or more seconds after completion of vibration in all three axes. After the observation period, perform the load test of 2.4.

3.10.3 The open circuit voltage of any BOL cell shall not change during the observation period of 3.10.2. BOL cells shall meet the applicable pass/fail criteria of the load test of 2.4. EOL cells shall not leak, vent, rupture, or explode. For information only, the BOL cells shall then be subjected to the high rate discharge test according to 3.5 and Appendix A herein.

3.11 REPORTING

For each lot subjected to the Acceptance and Lot Certification tests, the manufacturer shall forward to NASA a short report in the format outlined in Appendix B showing the results of each test performed.

APPENDIX A

Cell/Battery Size (ANSI)	WGL Dwg. No.	Capacity Discharge Load-Ohms (3.3)	High Rate Discharge Load-Ohms (3.5)	Short Circuit milli-ohms (3.8)	Load Check Ohms (2.4)	Minimum Average Capacity Required Amp-hrs (3.3)	Allowable Weight Grams (2.6)	Cell Diameter Inches (nom.)	Cell Length Inches (nom.)	Wt tol %
AA	3B39	182	30	50	30	1.8	16.05 ± 0.45	0.54	1.92	
C	3B464	75	6	50	10	6.5	55 ± 3	1.009	1.91	5.45
C	3B2075-XA	75	6	50	10	6.0	55 ± 2	1.009	1.91	3.64
C	3B2892	75	6	500	10	6.5	59 ± 1	1.009	1.91	1.70
D	3B1910-XA	20	3	50	5	13.0	114 ± 2	1.32	2.34	1.75
2D	3PD310*	40	6	50	10	13.0	227 ± 5	1.32	4.89	2.2
DD	3B2085-XA	10	1.5	50	2.25	25.0	212 ± 4	1.32	4.38	1.89
DD	3B3100	2.5	1.0	325	2.5	25.0	210 ± 5	1.32	4.395	2.38

* Cell Drawings are 3B1910XB and 3B1910XC, for purposes of certain acceptance tests done at cell level.

NOTES:

1. Drawings will bear a revision as shown on the NASA order/contract, unless otherwise approved by the NASA Contracting Officer in writing.

2. All resistances shall have a tolerance not exceeding ±1% of the nominal value.

3. Applicable test paragraph numbers are shown in parentheses in the title blocks.

APPENDIX B

OUTLINE OF ACCEPTANCE AND LOT CERTIFICATION TEST REPORT

1.0 ACCEPTANCE TEST (2.0)

1.1 Serialization (2.2)

a. Lot number and quantity (each cell size)
b. Serial number (each cell)

1.2 160°F Exposure (2.1)

a. Data sheet (approved) showing temperature exposure and thermocouple location (2.1.1)
b. Cell voltage (OCV) and serial number (S/N) (2.3)
c. Cell S/N, time load voltage reached 3.50 V and load voltage at 90 ± 10 seconds (2.4)
d. Cell S/N, diameter, length and weight (2.5 and 2.6)

1.3 X-rays (2.7)

a. Cell X-rays with serial number (2-views per cell minimum)
b. Date X-rays taken
c. Statement of examination results

2.0 LOT CERTIFICATION (3.0)

2.1 Lot Definition (3.1)

a. Lot number and quantity
b. Manufacturing date(s)

2.2 Capacity Discharge Test (3.3)

a. Date(s) of test
b. Sample size and cell S/N
c. Minimum average capacity requirement
d. Average capacity obtained
e. Individual cell capacities (attachment)

2.3 High Temperature Exposure (3.4)

a. Date(s) of test
b. Sample size and S/N
c. Test results (no leaks or vents, or quantity of leaks or vents)

2.4 High Rate Discharge (3.5)

a. Date(s) of test
b. Load used
c. Individual cell capacities (attachment) by S/N

2.5 Fuse Check Test (3.6)

a. Date(s) of test
b. Results of test (all pass or quantity failed)

2.6 Overdischarge Test (3.7)

a. Date(s) of test
b. Results of room temperature test and 160°F tests with diodes;

(1) No venting, or
(2) Quantity vented and duration of exposure at time of venting (attachment)

c. Results of 160°F continuation test without diodes;

(1) No venting, or
(2) Quantity vented and duration of exposure at time of venting (attachment)

2.7 Short Circuit Test (3.8)

a. Date(s) of test
b. Sample size and S/N
c. Peak current reached on each cell (attachment)
d. Temperature rise on each cell (attachment)
e. Time to reach peak current and peak temperature

2.8 Vibration Test (3.10)

a. Date(s) of test
b. Sample size and S/N's
c. Open circuit voltage during vibration test
d. Load voltage and load used
e. High rate discharge load and individual cell capacities (attachment)

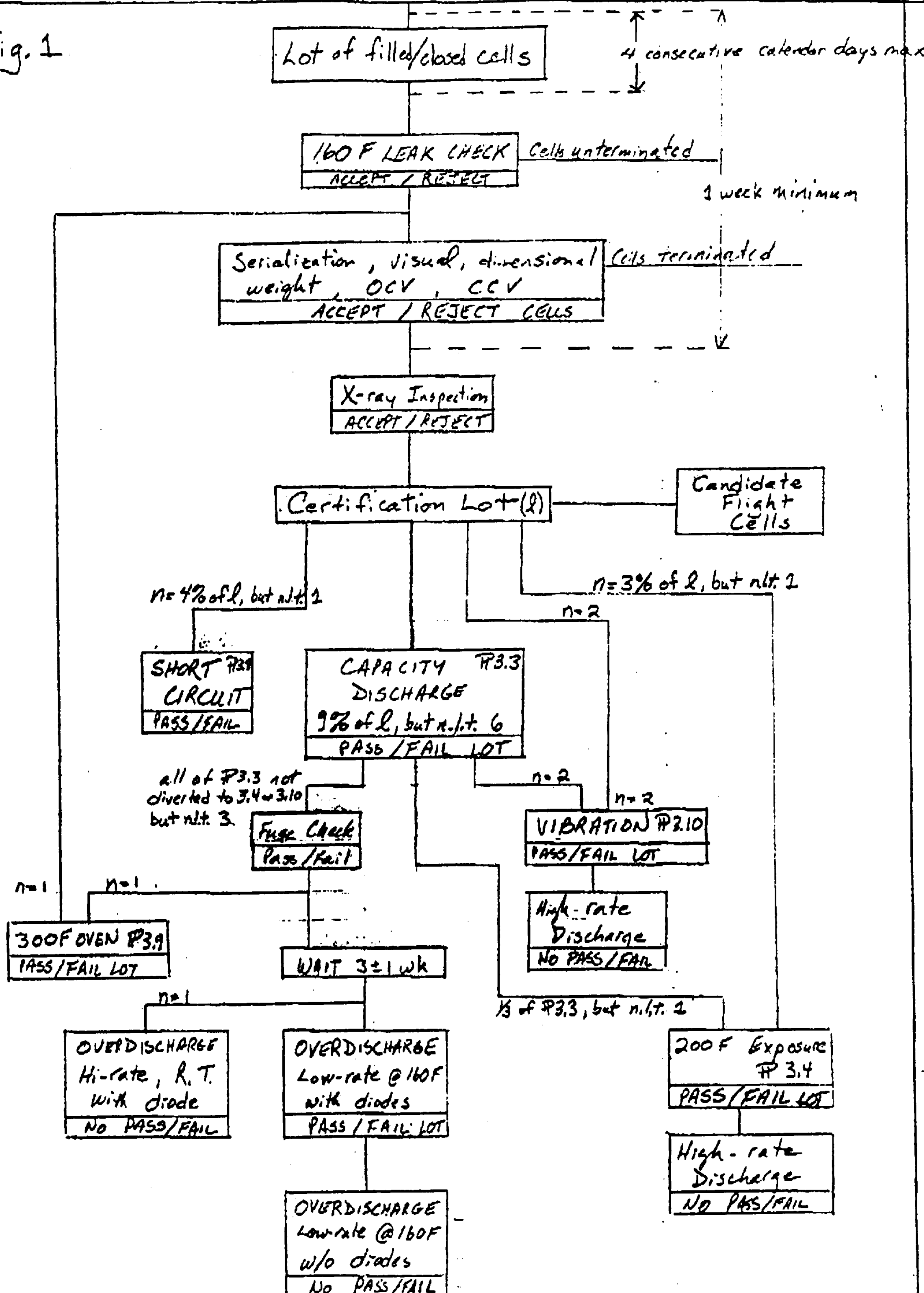
2.9 300°F Exposure Test (3.9)

a. Date(s) of test
b. Cell S/N
c. Description of cell after test

2.10 Copies of all failure/discrepancy reports with material review action on each.

2.11 Certification by the manufacturer's quality assurance manager and DPRO that all testing was performed according to requirements of this specification, and that this report is complete and accurate.

Fig. 1



l = lot size
n.l.t. = no less than

APPENDIX B

ANOVA REPORTS FOR 1A ROOM TEMPERATURE DISCHARGE

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
TEST 1A: FRESH 1A CONSTANT CURRENT DISCHARGE AT 25°C. OUTPUT IS VOLTAGE AT 1 SECOND.

Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.

Comment:
ANALYSIS OF START UP CAPABILITY AT 1A.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	3.38	3.39	3.4
Experiment # 2 :	2.25	2.4	2.54
Experiment # 3 :	2.98	2.96	2.78
Experiment # 4 :	3.51	3.51	3.54
Experiment # 5 :	1.72	1.55	1.52
Experiment # 6 :	3.27	2.99	2.96
Experiment # 7 :	3.58	3.55	3.59
Experiment # 8 :	2.92	2.5	2.76
Experiment # 9 :	3.15	2.92	2.96
Experiment # 10 :	3.44	3.41	3.43
Experiment # 11 :	3.29	3.34	3.3
Experiment # 12 :	3.51	3.45	3.4
Experiment # 13 :	3.6	3.56	3.53

....

Experiment # 14 :

3	3.35	3.32

....

Experiment # 15 :

3.57	3.54	3.43

....

Experiment # 16 :

3.6	3.58	3.57

....

Experiment # 17 :

3.39	3.33	3.43

....

Experiment # 18 :

3.47	3.51	3.46

....

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	3.75	3.75	49.08	3.67	26.7	%***
B	2	.42	.21	2.75	.27	1.94	%
C	2	5	2.5	32.73	4.85	35.24	%***
D	2	1.07	.54	7.02	.92	6.68	%***
e	46	3.51	.08		4.05	29.43	%
Total	53	13.76				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence   ** = 99% Confidence   *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54   Correction Factor = 543.97
Sum (experiment values) = 171.39   Sum of sqs (experiment values) = 13.76

R E S P O N S E T A B L E

Factor:	A	B	C	D	-
LEVEL 1	78.58	56.65	63.17	60.38	-
LEVEL 2	92.81	55.47	49.91	54.19	-
LEVEL 3	-	59.27	58.31	56.82	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

R E S P O N S E T A B L E (A V E R A G E S)

Factor:	A	B	C	D	-
LEVEL 1	2.91	3.15	3.51	3.35	-
LEVEL 2	3.44	3.08	2.77	3.01	-
LEVEL 3	-	3.29	3.24	3.16	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

M A I N E F F E C T S A N A L Y S I S

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	3.44
CELL DESIGN	JPL D	3	3.29
DEPOLARIZER TYPE	BCX	1	3.51
ELECTTROLYTE CONC.	0.6M	1	3.35

Total Contribution from significant factors =
13.59
Average Total for all results = 3.17
Estimate of average result (optimum) =
4.07

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY
Goal/Objective:
TEST 1A: FRESH 1A CONSTANT CURRENT DISCHARGE AT 25°C. OUTPUT IS VOLTAGE AT 5 SECONDS.
Comment:
ANALYSIS OF START UP CAPACILITY AT 1A.
Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	3.49	3.51	3.53
Experiment # 2 :	2.34	2.45	2.49
Experiment # 3 :	3.22	3.09	3.09
Experiment # 4 :	3.58	3.59	3.61
Experiment # 5 :	2.19	2.22	1.99
Experiment # 6 :	3.25	3.11	3.09
Experiment # 7 :	3.61	3.58	3.59
Experiment # 8 :	2.75	2.69	2.84
Experiment # 9 :	3.22	3.22	3.29
Experiment # 10 :	3.55	3.53	3.59
Experiment # 11 :	3.14	3.18	3.16
Experiment # 12 :	3.43	3.42	3.41
Experiment # 13 :	3.67	3.62	3.61
Experiment # 14 :			

3.26 3.3 3.24

....

Experiment # 15 :

3.5 3.49 3.43

....

Experiment # 16 :

3.64 3.66 3.63

....

Experiment # 17 :

3.27 3.24 3.29

....

Experiment # 18 :

3.53 3.55 3.5

....

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	1.93	1.93	69.26	1.9	20.56	%***
B	2	.22	.11	3.88	.16	1.74	%*
C	2	5.25	2.63	94.21	5.2	56.15	%***
D	2	.57	.29	10.27	.52	5.59	%***
e	46	1.28	.03		1.48	15.96	%
Total	53	9.25				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54 Correction Factor = 570.18
Sum (experiment values) = 175.47 Sum of sqs (experiment values) = 9.25

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	82.63	57.62	64.59	60.74	-
LEVEL 2	92.84	57.75	51.04	56.2	-
LEVEL 3	-	60.1	59.84	58.53	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	3.06	3.2	3.59	3.37	-
LEVEL 2	3.44	3.21	2.84	3.12	-
LEVEL 3	-	3.34	3.32	3.25	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY

Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	3.44
CELL DESIGN	JPL D	3	3.34
DEPOLARIZER TYPE	BCX	1	3.59
ELECTTROLYTE CONC.	0.6M	1	3.37

Total Contribution from significant factors =
13.74

Average Total for all results = 3.25

Estimate of average result (optimum) =
3.99

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
TEST 1A: FRESH 1A DISCHARGE AT 25°C. OUTPUT IS VOLTAGE AT 60 SECONDS

Procedure:
ANALYSIS OF START UP CAPABILITY AT 1A.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	3.59	3.63	3.63
Experiment # 2 :	2.96	2.89	2.92
Experiment # 3 :	3.36	3.33	3.34
Experiment # 4 :	3.67	3.62	3.7
Experiment # 5 :	2.99	2.97	3
Experiment # 6 :	3.35	3.36	3.37
Experiment # 7 :	3.65	3.62	3.63
Experiment # 8 :	3.14	3.07	3.12
Experiment # 9 :	3.36	3.36	3.38
Experiment # 10 :	3.65	3.62	3.65
Experiment # 11 :	2.95	2.94	2.93
Experiment # 12 :	3.33	3.35	3.35
Experiment # 13 :	3.74	3.68	3.69
Experiment # 14 :			

3.2 3.17 3.12

....

Experiment # 15 :

3.37 3.36 3.32

....

Experiment # 16 :

3.69 3.71 3.67

....

Experiment # 17 :

3.04 3.04 3.06

....

Experiment # 18 :

3.48 3.49 3.45

....

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	.02	.02	10.22	.02	.48	%***
B	2	.07	.04	19.07	.07	1.87	%***
C	2	3.58	1.79	912.32	3.57	94.27	%***
D	2	.03	.01	7.23	.02	.64	%***
e	46	.09	.002		.1	2.74	%
Total	53	3.79				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54 Correction Factor = 607.09
Sum (experiment values) = 181.06 Sum of sqs (experiment values) = 3.79

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	90.01	59.42	65.84	59.95	-
LEVEL 2	91.05	60.68	54.51	60.19	-
LEVEL 3	-	60.96	60.71	60.92	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	3.33	3.3	3.66	3.33	-
LEVEL 2	3.37	3.37	3.03	3.34	-
LEVEL 3	-	3.39	3.37	3.38	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	3.37
CELL DESIGN	JPL D	3	3.39
DEPOLARIZER TYPE	BCX	1	3.66
ELECTTROLYTE CONC.	1.8M	3	3.38

Total Contribution from significant factors = 13.8
Average Total for all results = 3.35
Estimate of average result (optimum) = 3.74

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
TEST 1A:FRESH 1A CONSTANT CURRENT DISCHARGE AT 25°C. OUTPUT IS RUNNING VOLTAGE (50%DOD).

Procedure:
ANALYSIS OF RUNNING VOLTAGE.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	3.16	3.19	3.18
Experiment # 2 :	3.13	3.13	3.1
Experiment # 3 :	3.2	3.21	3.21
Experiment # 4 :	3.28	3.22	3.26
Experiment # 5 :	3.18	3.17	3.19
Experiment # 6 :	3.15	3.28	3.29
Experiment # 7 :	3.4	3.37	3.36
Experiment # 8 :	3.29	3.32	3.31
Experiment # 9 :	3.33	3.31	3.34
Experiment # 10 :	3.35	3.27	3.34
Experiment # 11 :	3.09	3.07	3.13
Experiment # 12 :	3.19	3.28	3.35
Experiment # 13 :	3.38	3.28	3.36

Experiment # 14 :

3.3 3.32 3.27

....

Experiment # 15 :

3.26 3.29 3.25

....

Experiment # 16 :

3.42 3.43 3.4

....

Experiment # 17 :

3.24 3.23 3.26

....

Experiment # 18 :

3.47 3.46 3.43

....

A N A L Y S I S   O F   V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)
A	1	.05	.05	27.84	.04	8.55 %***
B	2	.22	.11	67.47	.22	42.33 %***
C	2	.12	.06	35.88	.11	22.21 %***
D	2	.05	.03	16.75	.05	10.03 %***
e	46	.07	.0016		.09	16.88 %
Total	53	.51				100.00 %

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence   ** = 99% Confidence   *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY

Number of experiments = 54   Correction Factor = 578.07

Sum (experiment values) = 176.68   Sum of sqs (experiment values) = .51

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	87.56	57.58	59.65	58.09	-
LEVEL 2	89.12	58.73	57.73	59.23	-
LEVEL 3	-	60.37	59.3	59.36	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	3.24	3.2	3.31	3.23	-
LEVEL 2	3.3	3.26	3.21	3.29	-
LEVEL 3	-	3.35	3.29	3.3	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	3.3
CELL DESIGN	JPL D	3	3.35
DEPOLARIZER TYPE	BCX	1	3.31
ELECTTROLYTE CONC.	1.8M	3	3.3

Total Contribution from significant factors = 13.26
Average Total for all results = 3.27
Estimate of average result (optimum) = 3.44

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
TEST 1A: FRESH 1A CONSTANT CURRENT DISCHARGE AT 25°C. OUTPUT IS 2.0V CAPACITY (AHRS)

Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	5.75	6.58	6.04
Experiment # 2 :	8.27	7.98	8.14
Experiment # 3 :	14.18	14.13	13.69
Experiment # 4 :	6.6	7.42	6.5
Experiment # 5 :	4.9	5.1	5.82
Experiment # 6 :	12.15	12.67	12.53
Experiment # 7 :	9.94	9.2	9.48
Experiment # 8 :	5.99	6.03	9.33
Experiment # 9 :	9.64	9.53	9.64
Experiment # 10 :	9.65	11.32	10.6
Experiment # 11 :	7.41	7.55	8.26
Experiment # 12 :	13.11	13.15	13.24
Experiment # 13 :	10.99	11.02	10.67
Experiment # 14 :			

11.06	10.7	11.19

....

Experiment # 15 :

11.76	11.95	12.71

....

Experiment # 16 :

9.3	9.59	8.54

....

Experiment # 17 :

10.75	10.53	10.46

....

Experiment # 18 :

10.08	10.4	10.14

....

A N A L Y S I S   O F   V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	44.28	44.28	19.67	42.03	13.11	%***
B	2	3.19	1.59	.71	0	0	%
C	2	137.61	68.8	30.56	133.1	41.52	%***
D	2	31.97	15.98	7.1	27.47	8.57	%***
e	46	103.57	2.25		118.02	36.81	%
Total	53	320.62				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54 Correction Factor = 5072.33
Sum (experiment values) = 523.36 Sum of sqs (experiment values) = 320.62

R E S P O N S E   T A B L E

Factor:	A	B	C	D	-
LEVEL 1	237.23	179.05	159.19	159.08	-
LEVEL 2	286.13	175.74	149.47	171.63	-
LEVEL 3	-	168.57	214.7	192.65	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

R E S P O N S E   T A B L E   (A V E R A G E S)

Factor:	A	B	C	D	-
LEVEL 1	8.79	9.95	8.84	8.84	-
LEVEL 2	10.6	9.76	8.3	9.54	-
LEVEL 3	-	9.37	11.93	10.7	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

M A I N   E F F E C T S   A N A L Y S I S

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	10.6
CELL DESIGN	NASA149 D	1	9.95
DEPOLARIZER TYPE	CSC	3	11.93
ELECTTROLYTE CONC.	1.8M	3	10.7

Total Contribution from significant factors = 43.18
Average Total for all results = 9.69
Estimate of average result (optimum) = 14.1

APPENDIX C

ANOVA REPORTS FOR 1A -25°C DISCHARGE

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY
Goal/Objective:
TEST 1B: FRESH 1A DISHCARGE AT -25°C. OUTPUT IS 1 SECOND VOLTAGE.
Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.
Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	2.98	3.03	3.07
Experiment # 2 :	0	0	0
Experiment # 3 :	2.88	0	0
Experiment # 4 :	3.3	3.36	3.35
Experiment # 5 :	2.12	1.59	1.72
Experiment # 6 :	2.84	2.8	2.8
Experiment # 7 :	2.17	1.81	2.47
Experiment # 8 :	2.9	2.94	2.91
Experiment # 9 :	2.98	2.9	3.01
Experiment # 10 :	2.28	2.79	2.48
Experiment # 11 :	3.16	2.88	3.1
Experiment # 12 :	2.45	2.51	2.29
Experiment # 13 :	3.46	3.43	3.4
Experiment # 14 :			

3.02 3.05 2.92

....

Experiment # 15 :

3.25 3.26 3.27

....

Experiment # 16 :

3.33 3.38 3.38

....

Experiment # 17 :

3.27 3.26 3.27

....

Experiment # 18 :

3.22 3.23 3.21

....

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)
A	1	9.48	9.48	27.75	9.13	18.76 %***
B	2	11.21	5.61	16.42	10.53	21.63 %***
C	2	3.61	1.81	5.29	2.93	6.02 %**
D	2	8.68	4.34	12.71	7.99	16.42 %***
e	46	15.71	.34		18.1	37.17 %
Total	53	48.69				100.00 %

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54   Correction Factor = 375.94
Sum (experiment values) = 142.48   Sum of sqs (experiment values) = 48.69

R E S P O N S E   T A B L E

Factor:	A	B	C	D	-
EVEL 1	59.93	35.9	53.47	56.7	-
LEVEL 2	82.55	52.94	42.11	39.08	-
LEVEL 3	-	53.64	46.9	46.7	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

R E S P O N S E   T A B L E   (A V E R A G E S)

Factor:	A	B	C	D	-
LEVEL 1	2.22	1.99	2.97	3.15	-
LEVEL 2	3.06	2.94	2.34	2.17	-
LEVEL 3	-	2.98	2.61	2.59	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

M A I N   E F F E C T S   A N A L Y S I S

NASA D CELL COMPARISON STUDY

Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	3.06
CELL DESIGN	JPL D	3	2.98
DEPOLARIZER TYPE	BCX	1	2.97
ELECTTROLYTE CONC.	0.6M	1	3.15

Total Contribution from significant factors = 12.16

Average Total for all results = 2.64

Estimate of average result (optimum) = 4.24

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY
Goal/Objective:
TEST 1B: FRESH 1A DISHCARGE AT -25°C. OUTPUT IS 5 SECOND VOLTAGE.
Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.
Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	3.24	3.26	3.27
Experiment # 2 :	0	0	0
Experiment # 3 :	2.65	0	0
Experiment # 4 :	3.4	3.43	3.42
Experiment # 5 :	0	0	0
Experiment # 6 :	2.46	2.18	2.27
Experiment # 7 :	2.22	0	.74
Experiment # 8 :	2.38	2.13	0
Experiment # 9 :	2.88	2.53	2.91
Experiment # 10 :	3.16	3.3	3.27
Experiment # 11 :	3.05	2.93	3.05
Experiment # 12 :	2.49	2.54	2.5
Experiment # 13 :	3.45	3.46	3.45
Experiment # 14 :			

2.95	3.11	2.83

Experiment # 15 :

3.27	3.28	3.28

Experiment # 16 :

3.35	3.34	3.35

Experiment # 17 :

3.21	3.21	3.22

Experiment # 18 :

3.24	3.24	3.24

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	28.75	28.75	63.52	28.29	34.04	%***
B	2	1.85	.92	2.04	.94	1.13	%
C	2	12.5	6.25	13.82	11.6	13.95	%***
D	2	19.21	9.6	21.22	18.3	22.02	%***
e	46	20.82	.45		23.98	28.85	%
Total	53	83.12				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54
Sum (experiment values) = 130.14
Correction Factor = 313.64
Sum of sqs (experiment values) = 83.12

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	45.37	38.71	53.11	56.84	-
LEVEL 2	84.77	46.24	32.07	30.57	-
LEVEL 3	-	45.19	44.96	42.73	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	1.68	2.15	2.95	3.16	-
LEVEL 2	3.14	2.57	1.78	1.7	-
LEVEL 3	-	2.51	2.5	2.37	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY

Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	3.14
CELL DESIGN	UNIV D	2	2.57
DEPOLARIZER TYPE	BCX	1	2.95
ELECTTROLYTE CONC.	0.6M	1	3.16

Total Contribution from significant factors = 11.82

Average Total for all results = 2.41

Estimate of average result (optimum) = 4.59

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
TEST 1B: FRESH 1A DISHCARGE AT -25°C. OUTPUT IS 60 SECOND VOLTAGE.

Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS (3 Trial(s) per Experiment)

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	3.44	3.44	3.44
Experiment # 2 :	0	0	0
Experiment # 3 :	1.81	2.62	2.66
Experiment # 4 :	3.51	3.53	3.52
Experiment # 5 :	2.75	2.74	2.74
Experiment # 6 :	2.71	2.71	2.72
Experiment # 7 :	1.86	0	0
Experiment # 8 :	2.82	2.8	2.78
Experiment # 9 :	2.73	2.7	2.71
Experiment # 10 :	3.32	3.4	3.39
Experiment # 11 :	2.73	2.71	2.73
Experiment # 12 :	2.56	2.56	2.63
Experiment # 13 :	3.51	3.52	3.52
Experiment # 14 :			

2.6	2.74	2.53

....

Experiment # 15 :

2.8	2.7	2.69

....

Experiment # 16 :

3.42	3.41	3.41

....

Experiment # 17 :

2.85	2.85	2.86

....

Experiment # 18 :

2.75	2.76	2.76

....

A N A L Y S I S O F V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	5.33	5.33	10.29	4.81	10.35	%***
B	2	3.17	1.59	3.06	2.14	4.59	%
C	2	4.28	2.14	4.13	3.24	6.97	%*
D	2	9.88	4.94	9.54	8.85	19.03	%***
e	46	23.83	.52		27.46	59.06	%
Total	53	46.5				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54 Correction Factor = 375.78
Sum (experiment values) = 142.45 Sum of sqs (experiment values) = 46.5

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	62.74	43.44	53.64	53.94	-
LEVEL 2	79.71	53.54	41.23	36.66	-
LEVEL 3	-	45.47	47.58	51.85	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	2.32	2.41	2.98	3	-
LEVEL 2	2.95	2.97	2.29	2.04	-
LEVEL 3	-	2.53	2.64	2.88	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	2.95
CELL DESIGN	UNIV D	2	2.97
DEPOLARIZER TYPE	BCX	1	2.98
ELECTTROLYTE CONC.	0.6M	1	3

Total Contribution from significant factors = 11.9
Average Total for all results = 2.64
Estimate of average result (optimum) = 3.99

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY
Goal/Objective:
TEST 1B: FRESH 1A DISHCARGE AT -25°C. OUTPUT IS RUNNING VOLTAGE AT 50% DOD.
Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.
Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	3.36	3.37	3.29
Experiment # 2 :	2.72	2.72	2.4
Experiment # 3 :	2.77	2.79	2.81
Experiment # 4 :	2.9	2.86	2.77
Experiment # 5 :	2.75	2.73	2.82
Experiment # 6 :	2.93	2.9	2.92
Experiment # 7 :	2.24	2.69	2.7
Experiment # 8 :	3.03	3.02	3.01
Experiment # 9 :	2.9	2.88	2.87
Experiment # 10 :	2.64	2.71	3.41
Experiment # 11 :	2.81	2.82	2.82
Experiment # 12 :	2.8	2.8	2.8
Experiment # 13 :	2.86	2.83	2.87
Experiment # 14 :			

2.92	2.95	2.9

Experiment # 15 :

2.81	2.86	2.84

Experiment # 16 :

2.93	2.88	2.86

Experiment # 17 :

2.93	2.93	2.92

Experiment # 18 :

2.86	2.75	2.92

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	.0015	.0015	.04	0	0	%
B	2	.01	.0042	.13	0	0	%
C	2	.03	.02	.53	0	0	%
D	2	.44	.22	6.75	.37	18.88	%***
e	46	1.49	.03		1.6	81.12	%
Total	53	1.97				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54 Correction Factor = 442.5
Sum (experiment values) = 154.58 Sum of sqs (experiment values) = 1.97

R E S P O N S E   T A B L E

Factor:	A	B	C	D	-
LEVEL 1	77.15	51.84	52.17	52.94	-
LEVEL 2	77.43	51.42	51.2	49.26	-
LEVEL 3	-	51.32	51.21	52.38	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

R E S P O N S E   T A B L E   (A V E R A G E S)

Factor:	A	B	C	D	-
LEVEL 1	2.86	2.88	2.9	2.94	-
LEVEL 2	2.87	2.86	2.84	2.74	-
LEVEL 3	-	2.85	2.85	2.91	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

M A I N   E F F E C T S   A N A L Y S I S

NASA D CELL COMPARISON STUDY

Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	2.87
CELL DESIGN	NASA149 D	1	2.88
DEPOLARIZER TYPE	BCX	1	2.9
ELECTTROLYTE CONC.	0.6M	1	2.94

Total Contribution from significant factors = 11.59

Average Total for all results = 2.86

Estimate of average result (optimum) = 3

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
TEST 1B: FRESH 1A DISHCARGE AT -25°C. OUTPUT IS CAPACITY TO 2.0V.

Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	2.78	2.83	2.96
Experiment # 2 :	3.02	2.92	2.68
Experiment # 3 :	7.48	8.84	8.54
Experiment # 4 :	4.08	3.83	3.62
Experiment # 5 :	1.97	2.2	1.91
Experiment # 6 :	3.8	5.41	6.86
Experiment # 7 :	3.91	6.21	6.37
Experiment # 8 :	2.26	2.15	2.66
Experiment # 9 :	4.26	7.7	5.76
Experiment # 10 :	4.36	4.96	.45
Experiment # 11 :	4.46	4.67	4.44
Experiment # 12 :	3.89	3.96	4.09
Experiment # 13 :	4.03	3.14	4.48

Experiment # 14 :

9.44	9.34	9.04

Experiment # 15 :

3.43	3.96	3.7

Experiment # 16 :

7.4	6.1	5.49

Experiment # 17 :

9.36	9.3	9.09

Experiment # 18 :

9.71	8.95	9.45

A N A L Y S I S   O F   V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)
A	1	35.33	35.33	7.67	30.73	9.08 %**
B	2	47.6	23.8	5.17	38.39	11.35 %**
C	2	30.09	15.05	3.27	20.89	6.17 %*
D	2	13.52	6.76	1.47	4.31	1.28 %
e	46	211.79	4.6		244.02	72.12 %
Total	53	338.34				100.00 %

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence   ** = 99% Confidence   *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY

Number of experiments = 54
Correction Factor = 1428.1
Sum (experiment values) = 277.7
Sum of sqs (experiment values) = 338.34

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	117.01	77.33	77	90.23	-
LEVEL 2	160.69	84.24	90.91	82.89	-
LEVEL 3	-	116.13	109.79	104.58	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	4.33	4.3	4.28	5.01	-
LEVEL 2	5.95	4.68	5.05	4.61	-
LEVEL 3	-	6.45	6.1	5.81	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	5.95
CELL DESIGN	JPL D	3	6.45
DEPOLARIZER TYPE	CSC	3	6.1
ELECTTROLYTE CONC.	1.8M	3	5.81

Total Contribution from significant factors = 24.31
Average Total for all results = 5.14
Estimate of average result (optimum) = 8.88

APPENDIX D

ANOVA REPORTS FOR 3A ROOM TEMPERATURE DISCHARGE

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
TEST 1B: FRESH 3A CONSTANT CURRENT DISCHARGE AT 25°C. OUTPUT IS 1 SECOND VOLTAGE.

Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	3.03	3.03	2.98
Experiment # 2 :	0	0	0
Experiment # 3 :	2.79	.55	.13
Experiment # 4 :	3.23	3.24	3.19
Experiment # 5 :	2.87	0	0
Experiment # 6 :	1.04	2.71	1.25
Experiment # 7 :	2.91	1.19	1.85
Experiment # 8 :	.21	1.26	0
Experiment # 9 :	1.42	1.21	.79
Experiment # 10 :	2.8	3.12	2.95
Experiment # 11 :	2.81	2.65	2.88
Experiment # 12 :	2.76	3.02	2.94
Experiment # 13 :	3.31	3.33	3.31
Experiment # 14 :			

3.08	3.04	3.05

....

Experiment # 15 :

3.15	3.13	3.11

....

Experiment # 16 :

3.4	3.35	3.36

....

Experiment # 17 :

3	3.05	3.05

....

Experiment # 18 :

3.17	3.18	3.17

....

A N A L Y S I S   O F   V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	33.12	33.12	70.55	32.65	43	%***
B	2	1.87	.93	1.99	.93	1.22	%
C	2	14.5	7.25	15.45	13.57	17.87	%***
D	2	4.85	2.42	5.16	3.91	5.15	%**
e	46	21.59	.47		24.88	32.77	%
Total	53	75.93				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence   ** = 99% Confidence   *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54   Correction Factor = 284.97
Sum (experiment values) = 124.05   Sum of sqs (experiment values) = 75.93

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	40.88	38.44	53.58	48.95	-
LEVEL 2	83.17	46.04	30.95	37.01	-
LEVEL 3	-	39.57	39.52	38.09	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	1.51	2.14	2.98	2.72	-
LEVEL 2	3.08	2.56	1.72	2.06	-
LEVEL 3	-	2.2	2.2	2.12	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	3.08
CELL DESIGN	UNIV D	2	2.56
DEPOLARIZER TYPE	BCX	1	2.98
ELECTTROLYTE CONC.	0.6M	1	2.72

Total Contribution from significant factors = 11.34

Average Total for all results = 2.3

Estimate of average result (optimum) = 4.45

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
TEST 1B: FRESH 3A CONSTANT CURRENT DISCHARGE AT 25°C. OUTPUT IS 5 SECOND VOLTAGE.

Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	3.18	3.2	3.16
Experiment # 2 :	0	0	0
Experiment # 3 :	2.97	2.55	2.49
Experiment # 4 :	3.35	3.36	3.31
Experiment # 5 :	2.55	0	0
Experiment # 6 :	2.85	3	2.81
Experiment # 7 :	3.04	1.32	1.96
Experiment # 8 :	2.67	2.55	2.61
Experiment # 9 :	2.79	2.74	2.79
Experiment # 10 :	3	3.27	3.16
Experiment # 11 :	2.63	2.62	2.58
Experiment # 12 :	2.73	2.95	2.93
Experiment # 13 :	3.43	3.41	3.41

Experiment # 14 :

3.01 2.97 2.98

....

Experiment # 15 :

3.03 3 2.99

....

Experiment # 16 :

3.45 3.45 3.42

....

Experiment # 17 :

2.84 2.84 2.85

....

Experiment # 18 :

3.2 3.21 3.19

....

A N A L Y S I S   O F   V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	8.4	8.4	27.36	8.09	17.41	%***
B	2	1.76	.88	2.86	1.14	2.46	%
C	2	12.84	6.42	20.91	12.23	26.3	%***
D	2	9.37	4.68	15.26	8.76	18.83	%***
e	46	14.13	.31		16.28	35	%
Total	53	46.5				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence   ** = 99% Confidence   *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY

Number of experiments = 54   Correction Factor = 382.93

Sum (experiment values) = 143.8   Sum of sqs (experiment values) = 46.5

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	61.25	43.42	55.88	53.26	-
LEVEL 2	82.55	49.46	35.7	37.33	-
LEVEL 3	-	50.92	52.22	53.21	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	2.27	2.41	3.1	2.96	-
LEVEL 2	3.06	2.75	1.98	2.07	-
LEVEL 3	-	2.83	2.9	2.96	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	3.06
CELL DESIGN	JPL D	3	2.83
DEPOLARIZER TYPE	BCX	1	3.1
ELECTTROLYTE CONC.	0.6M	1	2.96

Total Contribution from significant factors = 11.95

Average Total for all results = 2.66

Estimate of average result (optimum) = 3.96

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
TEST 1B: FRESH 3A CONSTANT CURRENT DISCHARGE. OUTPUT IS 60 SECOND VOLTAGE.

Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	3.31	3.34	3.28
Experiment # 2 :	2.4	2.4	2.49
Experiment # 3 :	3.02	2.92	2.94
Experiment # 4 :	3.47	3.48	3.43
Experiment # 5 :	.61	2.57	2.48
Experiment # 6 :	3.11	3.13	3.11
Experiment # 7 :	2.9	2.35	2.34
Experiment # 8 :	2.84	2.84	2.77
Experiment # 9 :	3.07	3.05	3.1
Experiment # 10 :	3.1	3.35	3.26
Experiment # 11 :	2.65	2.63	2.62
Experiment # 12 :	2.82	3	2.97
Experiment # 13 :	3.5	3.48	3.48
Experiment # 14 :			

2.79	2.76	2.77

....

Experiment # 15 :

3.05	3.03	3.03

....

Experiment # 16 :

3.48	3.51	3.46

....

Experiment # 17 :

2.85	2.85	2.85

....

Experiment # 18 :

3.24	3.24	3.23

....

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	.72	.72	6.65	.61	5.36	%*
B	2	.06	.03	.28	0	0	%
C	2	4.51	2.25	20.74	4.29	37.44	%***
D	2	1.17	.59	5.39	.95	8.33	%**
e	46	5	.11		5.6	48.88	%
Total	53	11.47				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54 Correction Factor = 472.59
Sum (experiment values) = 159.75 Sum of sqs (experiment values) = 11.47

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	76.75	52.5	58.52	55.09	-
LEVEL 2	83	53.28	46.17	49.5	-
LEVEL 3	-	53.97	55.06	55.16	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	2.84	2.92	3.25	3.06	-
LEVEL 2	3.07	2.96	2.57	2.75	-
LEVEL 3	-	3	3.06	3.06	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	3.07
CELL DESIGN	JPL D	3	3
DEPOLARIZER TYPE	BCX	1	3.25
ELECTTROLYTE CONC.	1.8M	3	3.06

Total Contribution from significant factors = 12.38
Average Total for all results = 2.96
Estimate of average result (optimum) = 3.51

✓

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
TEST 1B: FRESH 3A CONSTANT CURRENT DISCHARGE. OUTPUT IS VOLTAGE AT 50% DOD.

Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	3.11	3.18	3.29
Experiment # 2 :	2.91	2.91	2.94
Experiment # 3 :	3.13	3.16	3.22
Experiment # 4 :	3.11	3.09	3.07
Experiment # 5 :	3.08	3.07	3.04
Experiment # 6 :	3.4	3.41	3.35
Experiment # 7 :	2.84	2.89	2.3
Experiment # 8 :	3.19	3.2	3.17
Experiment # 9 :	3.34	3.33	3.33
Experiment # 10 :	2.96	3.02	2.91
Experiment # 11 :	2.87	2.86	2.84
Experiment # 12 :	2.99	3.21	3.13
Experiment # 13 :	3.24	3.22	3.22
Experiment # 14 :			

2.65 2.59 2.58

....

Experiment # 15 :

3.22 3.17 3.18

....

Experiment # 16 :

3.27 3.28 3.25

....

Experiment # 17 :

3.19 3.18 3.18

....

Experiment # 18 :

3.35 3.34 3.33

....

A N A L Y S I S   O F   V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	.01	.01	.34	0	0	%
B	2	.15	.07	2.01	.08	2.79	%
C	2	.76	.38	10.12	.68	25.21	%***
D	2	.07	.03	.87	0	0	%
e	46	1.72	.04		1.95	72.01	%
Total	53	2.7				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence   ** = 99% Confidence   *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY

Number of experiments = 54

Sum (experiment values) = 167.29

Correction Factor = 518.26

Sum of sqs (experiment values) = 2.7

R E S P O N S E T A B L E

Factor:	A	B	C	D	-
LEVEL 1	84.06	54.64	55.25	56.54	-
LEVEL 2	83.23	55.69	53.45	55.01	-
LEVEL 3	-	56.96	58.59	55.74	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

R E S P O N S E T A B L E (A V E R A G E S)

Factor:	A	B	C	D	-
LEVEL 1	3.11	3.04	3.07	3.14	-
LEVEL 2	3.08	3.09	2.97	3.06	-
LEVEL 3	-	3.16	3.26	3.1	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

M A I N E F F E C T S A N A L Y S I S

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LAC	1	3.11
CELL DESIGN	JPL D	3	3.16
DEPOLARIZER TYPE	CSC	3	3.26
ELECTTROLYTE CONC.	0.6M	1	3.14

Total Contribution from significant factors =
12.67

Average Total for all results = 3.1
Estimate of average result (optimum) =
3.38

✓

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
TEST 1B: FRESH 3A CONSTANT CURRENT DISCHARGE. OUTPUT IS AHR TO 2.0V.

Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	2.24	2.42	2.26
Experiment # 2 :	4.05	4.63	4.43
Experiment # 3 :	11.31	11.19	12.11
Experiment # 4 :	4.74	5.44	5.23
Experiment # 5 :	6.34	5.45	6.15
Experiment # 6 :	11.85	11.8	11.89
Experiment # 7 :	8.03	7.52	6.33
Experiment # 8 :	9.24	9.26	9.72
Experiment # 9 :	9.25	9.23	9.43
Experiment # 10 :	5.62	5.88	5.79
Experiment # 11 :	3.41	3.24	3.8
Experiment # 12 :	10.14	10.35	9.66
Experiment # 13 :	8.04	8.11	8.11
Experiment # 14 :			

11.93 11.77 10.9

....

Experiment # 15 :

8.86 9.37 9.24

....

Experiment # 16 :

8.91 9.39 8.95

....

Experiment # 17 :

9.8 9.75 9.86

....

Experiment # 18 :

10.25 10.22 9.84

....

A N A L Y S I S   O F   V A R I A T I O N

'actor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	16.28	16.28	11.32	14.84	3.46	%***
B	2	86.46	43.23	30.07	83.58	19.46	%***
C	2	157.16	78.58	54.66	154.28	35.93	%***
D	2	103.42	51.71	35.97	100.55	23.41	%***
e	46	66.13	1.44		76.19	17.74	%
Total	53	429.45				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence   ** = 99% Confidence   *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54   Correction Factor = 3467.69
Sum (experiment values) = 432.73   Sum of sqs (experiment values) = 429.45

R E S P O N S E   T A B L E

Factor:	A	B	C	D	-
LEVEL 1	201.54	112.53	113.01	117.57	-
LEVEL 2	231.19	155.22	133.73	137.65	-
LEVEL 3	-	164.98	185.99	177.51	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

R E S P O N S E   T A B L E   (A V E R A G E S)

Factor:	A	B	C	D	-
LEVEL 1	7.46	6.25	6.28	6.53	-
LEVEL 2	8.56	8.62	7.43	7.65	-
LEVEL 3	-	9.17	10.33	9.86	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

M A I N   E F F E C T S   A N A L Y S I S

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	8.56
CELL DESIGN	JPL D	3	9.17
DEPOLARIZER TYPE	CSC	3	10.33
ELECTTROLYTE CONC.	1.8M	3	9.86

Total Contribution from significant factors =
37.92

Average Total for all results = 8.01

Estimate of average result (optimum) =
13.88

APPENDIX E

ANOVA REPORTS FOR 3A -25°C DISCHARGE

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
TEST 2B: FRESH 3A, -25°C CONSTANT CURRENT DISCHARGE. OUTPUT IS 1 SEC VOLTAGE.

Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	2.37	2.05	1.73
Experiment # 2 :	0	0	0
Experiment # 3 :	0	0	0
Experiment # 4 :	2.9	2.66	2.81
Experiment # 5 :	0	0	0
Experiment # 6 :	0	0	0
Experiment # 7 :	0	0	0
Experiment # 8 :	0	.79	0
Experiment # 9 :	2.31	2.3	2.4
Experiment # 10 :	1.45	2.24	2.26
Experiment # 11 :	2.56	2.63	2.6
Experiment # 12 :	2.2	2.08	1.93
Experiment # 13 :	3.06	3.08	3.05

Experiment # 14 :

2.52	2.59	2.48

Experiment # 15 :

2.72	2.7	2.71

Experiment # 16 :

3.07	3.08	3.08

Experiment # 17 :

3.11	3.08	3.06

Experiment # 18 :

2.89	2.93	2.98

A N A L Y S I S   O F   V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	45.96	45.96	169.27	45.69	53.47	%***
B	2	2.51	1.25	4.62	1.96	2.3	%*
C	2	5.19	2.59	9.55	4.65	5.44	%***
D	2	19.3	9.65	35.54	18.76	21.95	%***
e	46	12.49	.27		14.39	16.84	%
Total	53	85.45				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence   ** = 99% Confidence   *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54   Correction Factor = 165.24
Sum (experiment values) = 94.46   Sum of sqs (experiment values) = 85.45

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	22.32	26.1	38.89	46.7	-
LEVEL 2	72.14	33.28	25.42	24.2	-
LEVEL 3	-	35.08	30.15	23.56	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	.83	1.45	2.16	2.59	-
LEVEL 2	2.67	1.85	1.41	1.34	-
LEVEL 3	-	1.95	1.68	1.31	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	2.67
CELL DESIGN	JPL D	3	1.95
DEPOLARIZER TYPE	BCX	1	2.16
ELECTTROLYTE CONC.	0.6M	1	2.59

Total Contribution from significant factors =
9.37
Average Total for all results = 1.75
Estimate of average result (optimum) =
4.12

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY
Goal/Objective:
TEST 2B: FRESH 3A, -35°C CONSTANT CURRENT DISCHARGE. OUTPUT IS 5 SEC VOLTAGE.
Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.
Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	2.64	2.45	2.2
Experiment # 2 :	0	0	0
Experiment # 3 :	0	0	0
Experiment # 4 :	3.03	2.85	2.97
Experiment # 5 :	0	0	0
Experiment # 6 :	0	0	0
Experiment # 7 :	0	0	0
Experiment # 8 :	.14	1.88	.33
Experiment # 9 :	1.51	1.27	1.41
Experiment # 10 :	2.22	2.7	2.76
Experiment # 11 :	2.31	2.31	2.37
Experiment # 12 :	2.02	1.86	1.8
Experiment # 13 :	3.15	3.14	3.16
Experiment # 14 :			

2.17 2.21 2.17

....

Experiment # 15 :

2.47 2.39 2.47

....

Experiment # 16 :

3.11 3.12 3.12

....

Experiment # 17 :

2.66 2.64 2.61

....

Experiment # 18 :

2.59 2.62 2.66

....

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)
A	1	39.41	39.41	136.76	39.12	50.15 %***
B	2	.69	.34	1.19	.11	.14 %
C	2	12.29	6.15	21.33	11.72	15.02 %***
D	2	12.37	6.18	21.46	11.79	15.11 %***
e	46	13.26	.29		15.27	19.58 %
Total	53	78.01				100.00 %

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54 Correction Factor = 155.01
Sum (experiment values) = 91.49 Sum of sqs (experiment values) = 78.01

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	22.68	27.64	42.62	42.56	-
LEVEL 2	68.81	32.18	23.8	23	-
LEVEL 3	-	31.67	25.07	25.93	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	.84	1.54	2.37	2.36	-
LEVEL 2	2.55	1.79	1.32	1.28	-
LEVEL 3	-	1.76	1.39	1.44	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	2.55
CELL DESIGN	UNIV D	2	1.79
DEPOLARIZER TYPE	BCX	1	2.37
ELECTTROLYTE CONC.	0.6M	1	2.36

Total Contribution from significant factors =
9.07
Average Total for all results = 1.69
Estimate of average result (optimum) =
3.99

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
TEST 2B: FRESH 3A, -25°C CONSTANT CURRENT DISCHARGE. OUTPUT IS 60 SECOND VOLTAGE.

Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	2.97	2.92	2.96
Experiment # 2 :	0	0	0
Experiment # 3 :	1.27	.65	.58
Experiment # 4 :	3.21	3.16	3.18
Experiment # 5 :	1.27	1.02	1.3
Experiment # 6 :	2.4	2.4	2.32
Experiment # 7 :	0	0	0
Experiment # 8 :	2.56	2.51	2.55
Experiment # 9 :	1.94	2.1	2.21
Experiment # 10 :	1.25	1.3	2.8
Experiment # 11 :	2.44	2.43	2.44
Experiment # 12 :	2.27	2.26	2.21
Experiment # 13 :	3.25	3.23	3.27
Experiment # 14 :			

1.75	1.67	1.61

Experiment # 15 :

2.38	2.39	2.39

Experiment # 16 :

3.19	3.19	3.2

Experiment # 17 :

2.66	2.66	2.65

Experiment # 18 :

2.55	2.57	2.56

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	8.24	8.24	14.29	7.66	14.53	%***
B	2	3.9	1.95	3.38	2.74	5.2	%*
C	2	3.71	1.86	3.22	2.56	4.86	%*
D	2	10.38	5.19	9.01	9.23	17.5	%***
e	46	26.51	.58		30.54	57.91	%
Total	53	52.74				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54 Correction Factor = 232.5
Sum (experiment values) = 112.05 Sum of sqs (experiment values) = 52.74

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	45.48	30.75	43.08	47.09	-
LEVEL 2	66.57	42.2	31.52	27.76	-
LEVEL 3	-	39.1	37.45	37.2	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	1.68	1.71	2.39	2.62	-
LEVEL 2	2.47	2.34	1.75	1.54	-
LEVEL 3	-	2.17	2.08	2.07	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	2.47
CELL DESIGN	UNIV D	2	2.34
DEPOLARIZER TYPE	BCX	1	2.39
ELECTTROLYTE CONC.	0.6M	1	2.62

Total Contribution from significant factors =
9.82
Average Total for all results = 2.08
Estimate of average result (optimum) =
3.6

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
TEST 2B; FRESH 3A, -25°C CONSTANT CURRANT DISCHARGE. OUTPUT IS VOLTAGE AT 50% DOD.

Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS (3 Trial(s) per Experiment)

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	3.1	3.05	3.07
Experiment # 2 :	2.5	2.55	2.56
Experiment # 3 :	2.61	2.62	2.63
Experiment # 4 :	2.71	2.66	2.83
Experiment # 5 :	2.73	2.76	2.73
Experiment # 6 :	2.76	2.54	2.8
Experiment # 7 :	1.24	1.83	.82
Experiment # 8 :	2.86	2.9	2.89
Experiment # 9 :	2.78	2.58	2.84
Experiment # 10 :	2.08	2.12	2.16
Experiment # 11 :	2.62	2.59	2.59
Experiment # 12 :	2.6	2.6	2.57
Experiment # 13 :	2.8	2.66	2.75
Experiment # 14 :			

3.04	3.03	3.01

Experiment # 15 :

2.74	2.74	2.77

Experiment # 16 :

2.91	2.9	2.9

Experiment # 17 :

2.85	2.81	2.83

Experiment # 18 :

2.84	2.89	2.9

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	.21	.21	1.55	.07	.84	%
B	2	.44	.22	1.66	.18	2.02	%
C	2	.86	.43	3.21	.59	6.8	%*
D	2	1.03	.51	3.83	.76	8.72	%*
e	46	6.18	.13		7.12	81.62	%
Total	53	8.72				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence   ** = 99% Confidence   *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54   Correction Factor = 380.01
Sum (experiment values) = 143.25   Sum of sqs (experiment values) = 8.72

R E S P O N S E   T A B L E

Factor:	A	B	C	D	-
LEVEL 1	69.95	46.62	44.59	50.16	-
LEVEL 2	73.3	50.06	49.85	44.33	-
LEVEL 3	-	46.57	48.81	48.76	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

R E S P O N S E   T A B L E   (A V E R A G E S)

Factor:	A	B	C	D	-
LEVEL 1	2.59	2.59	2.48	2.79	-
LEVEL 2	2.71	2.78	2.77	2.46	-
LEVEL 3	-	2.59	2.71	2.71	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

M A I N   E F F E C T S   A N A L Y S I S

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	2.71
CELL DESIGN	UNIV D	2	2.78
DEPOLARIZER TYPE	TC	2	2.77
ELECTTROLYTE CONC.	0.6M	1	2.79

Total Contribution from significant factors =
11.05

Average Total for all results = 2.65
Estimate of average result (optimum) =
3.09

V

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
TEST 2B FRESH 3A, -25°C CONSTANT CURRENT DISCHARGE. OUTPUT IS CAPACITY TO 2.0V.

Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	1.31	1.65	1.27
Experiment # 2 :	1.85	1.72	1.7
Experiment # 3 :	5.17	5.1	6.08
Experiment # 4 :	2.82	2.68	2.59
Experiment # 5 :	2.76	2.66	2.66
Experiment # 6 :	8.28	9.11	8.56
Experiment # 7 :	0	0	0
Experiment # 8 :	3.92	2.52	2.71
Experiment # 9 :	7.87	7.61	8.09
Experiment # 10 :	4.16	3.77	3.61
Experiment # 11 :	2.39	2.42	2.42
Experiment # 12 :	3.02	2.59	2.55
Experiment # 13 :	5.65	4.19	4.89
Experiment # 14 :			

9.39 8.81 8.74

....

Experiment # 15 :

3.7	3.43	4.06

....

Experiment # 16 :

7.18	7.44	7.42

....

Experiment # 17 :

9.46	9.03	9.17

....

Experiment # 18 :

9.43	9.03	9.16

....

						ANALYSIS OF VARIATION
Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)
A	1	58.95	58.95	15.77	55.21	11.74 %***
B	2	97.9	48.95	13.09	90.42	19.22 %***
C	2	75.93	37.97	10.16	68.46	14.56 %***
D	2	65.6	32.8	8.77	58.13	12.36 %***
e	46	171.95	3.74		198.12	42.12 %
Total	53	470.33				100.00 %

(Note: Insignificant factors are pooled and indicated by parenthesis.)
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54 Correction Factor = 1230.76
Sum (experiment values) = 257.8 Sum of sqs (experiment values) = 470.33

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	100.69	52.78	60.63	81.97	-
LEVEL 2	157.11	94.98	84.33	63.86	-
LEVEL 3	-	110.04	112.84	111.97	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	3.73	2.93	3.37	4.55	-
LEVEL 2	5.82	5.28	4.69	3.55	-
LEVEL 3	-	6.11	6.27	6.22	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	5.82
CELL DESIGN	JPL D	3	6.11
DEPOLARIZER TYPE	CSC	3	6.27
ELECTTROLYTE CONC.	1.8M	3	6.22

Total Contribution from significant factors = 24.42
Average Total for all results = 4.77
Estimate of average result (optimum) = 10.1

APPENDIX F

ANOVA REPORTS FOR 1A ROOM TEMPERATURE DISCHARGE AFTER 1 YEAR

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY
Goal/Objective:
DETERMINE EFFECTS OF VARIOUS PARAMETERS ON 1A DISCHARGE AFTER 1 YEAR AT ROOM TEMPERATURE.
Procedure:
OUTPUT IS VOLTAGE AT 1 SECOND.

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.

3 DESIGN MATRICES BUILT FOR EACH TEST CONDITION.
Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	3.102	3.006	2.928
Experiment # 2 :	0	0	1.518
Experiment # 3 :	0	0	0
Experiment # 4 :	2.988	2.97	2.977
Experiment # 5 :	0	0	0
Experiment # 6 :	0	0	0
Experiment # 7 :	2.871	2.716	2.699
Experiment # 8 :	2.941	3.141	2.927
Experiment # 9 :	0	0	0
Experiment # 10 :	2.347	3.041	3.084
Experiment # 11 :	3.035	2.996	2.939
Experiment # 12 :	2.772	2.59	0

Experiment # 13 :

3.379	3.39	3.363

....

Experiment # 14 :

3.214	0	0

....

Experiment # 15 :

3.062	3.099	3.081

....

Experiment # 16 :

0	3.088	2.901

....

Experiment # 17 :

3.352	3.365	3.347

....

Experiment # 18 :

3.298	3.375	3.34

....

A N A L Y S I S O F V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	22.265	22.265	18.51	21.062	18.67	%***
B	2	4.51	2.255	1.88	2.105	1.87	%
C	2	20.026	10.013	8.33	17.621	15.62	%***
D	2	10.68	5.34	4.44	8.275	7.34	%*
e	46	55.325	1.203		63.744	56.51	%
Total	53	112.807				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54 Correction Factor = 216.969
Sum (experiment values) = 108.242 Sum of sqs (experiment values) = 112.807

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	36.784	33.358	50.85	46.247	-
LEVEL 2	71.458	31.523	32.775	35.311	-
LEVEL 3	-	43.361	24.617	26.684	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	1.362	1.853	2.825	2.569	-
LEVEL 2	2.647	1.751	1.821	1.962	-
LEVEL 3	-	2.409	1.368	1.482	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	2.647
CELL DESIGN	JPL D	3	2.409
DEPOLARIZER TYPE	BCX	1	2.825
ELECTTROLYTE CONC.	0.6M	1	2.569

Total Contribution from significant factors =
10.45
Average Total for all results = 2.004
Estimate of average result (optimum) =
4.437

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
DETERMINE EFFECTS OF VARIOUS PARAMETERS ON 1A DISCHARGE AFTER 1 YEAR AT ROOM TEMPERATURE.

Procedure:
OUTPUT IS VOLTAGE AT 5 SECONDS.

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.

3 DESIGN MATRICES BUILT FOR EACH TEST CONDITION.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	3.305	3.257	3.17
Experiment # 2 :	0	0	2.459
Experiment # 3 :	0	0	0
Experiment # 4 :	2.973	3.001	3.031
Experiment # 5 :	0	0	0
Experiment # 6 :	0	0	0
Experiment # 7 :	2.83	2.75	2.744
Experiment # 8 :	2.941	3.091	2.937
Experiment # 9 :	0	0	0
Experiment # 10 :	2.982	3.266	3.367
Experiment # 11 :	3.119	3.052	3.071
Experiment # 12 :	3.083	3.048	0

Experiment # 13 :

3.498	3.523	3.522

....

Experiment # 14 :

3.246	0	0

....

Experiment # 15 :

3.162	3.2	3.161

....

Experiment # 16 :

0	3.124	3.063

....

Experiment # 17 :

3.288	3.287	3.288

....

Experiment # 18 :

3.379	3.45	3.402

....

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)
A	1	24.123	24.123	18.52	22.821	18.97 %***
B	2	3.542	1.771	1.36	.937	.78 %
C	2	22.314	11.157	8.57	19.709	16.39 %***
D	2	10.398	5.199	3.99	7.794	6.48 %*
e	46	59.901	1.302		69.017	57.38 %
Total	53	120.278				100.00 %

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54
Sum (experiment values) = 113.07
Correction Factor = 236.756
Sum of sqs (experiment values) = 120.278

R E S P O N S E   T A B L E

Factor:	A	B	C	D	-
LEVEL 1	38.489	37.179	53.406	47.365	-
LEVEL 2	74.581	32.317	33.779	37.688	-
LEVEL 3	-	43.574	25.885	28.017	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

R E S P O N S E   T A B L E   (A V E R A G E S)

Factor:	A	B	C	D	-
LEVEL 1	1.426	2.066	2.967	2.631	-
LEVEL 2	2.762	1.795	1.877	2.094	-
LEVEL 3	-	2.421	1.438	1.557	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

M A I N   E F F E C T S   A N A L Y S I S

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	2.762
CELL DESIGN	JPL D	3	2.421
DEPOLARIZER TYPE	BCX	1	2.967
ELECTTROLYTE CONC.	0.6M	1	2.631

Total Contribution from significant factors =
10.781
Average Total for all results = 2.094
Estimate of average result (optimum) =
4.499

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY
Goal/Objective:
DETERMINE EFFECTS OF VARIOUS PARAMETERS ON 1A DISCHARGE AFTER 1 YEAR AT ROOM TEMPERATURE.
Procedure:
OUTPUT IS VOLTAGE AT 60 SECONDS.

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.

3 DESIGN MATRICES BUILT FOR EACH TEST CONDITION.
Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	3.489	3.461	3.339
Experiment # 2 :	0	0	2.677
Experiment # 3 :	0	0	0
Experiment # 4 :	3.053	3.011	3.018
Experiment # 5 :	0	0	0
Experiment # 6 :	0	0	0
Experiment # 7 :	2.915	2.841	2.847
Experiment # 8 :	2.973	3.126	2.998
Experiment # 9 :	0	0	0
Experiment # 10 :	3.282	3.249	3.444
Experiment # 11 :	2.959	2.936	2.987
Experiment # 12 :	3.219	3.258	0

Experiment # 13 :

3.554	3.58	3.579

Experiment # 14 :

3.269	0	0

Experiment # 15 :

3.213	3.212	3.186

Experiment # 16 :

0	3.141	3.116

Experiment # 17 :

3.217	3.21	3.207

Experiment # 18 :

3.333	3.384	3.365

A N A L Y S I S   O F   V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	22.883	22.883	16.85	21.524	17.44	%***
B	2	3.36	1.68	1.24	.644	.52	%
C	2	24.766	12.383	9.12	22.049	17.87	%***
D	2	9.932	4.966	3.66	7.216	5.85	%*
e	46	62.477	1.358		71.985	58.33	%
Total	53	123.418				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54   Correction Factor = 243.41
Sum (experiment values) = 114.648   Sum of sqs (experiment values) = 123.418

R E S P O N S E T A B L E

Factor:	A	B	C	D	-
LEVEL 1	39.748	38.3	54.919	47.498	-
LEVEL 2	74.9	32.675	33.559	38.552	-
LEVEL 3	-	43.673	26.17	28.598	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

R E S P O N S E T A B L E (A V E R A G E S)

Factor:	A	B	C	D	-
LEVEL 1	1.472	2.128	3.051	2.639	-
LEVEL 2	2.774	1.815	1.864	2.142	-
LEVEL 3	-	2.426	1.454	1.589	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

M A I N E F F E C T S A N A L Y S I S

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	2.774
CELL DESIGN	JPL D	3	2.426
DEPOLARIZER TYPE	BCX	1	3.051
ELECTTROLYTE CONC.	0.6M	1	2.639

Total Contribution from significant factors = 10.89
Average Total for all results = 2.123
Estimate of average result (optimum) = 4.521

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
DETERMINE EFFECTS OF VARIOUS PARAMETERS ON 1A DISCHARGE AFTER 1 YEAR AT ROOM TEMPERATURE.

Procedure:
OUTPUT IS VOLTAGE AT 50% DOD.

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.

3 DESIGN MATRICES BUILT FOR EACH TEST CONDITION.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	3.149	3.1	3.113
Experiment # 2 :	0	0	3.052
Experiment # 3 :	0	0	0
Experiment # 4 :	2.894	2.959	2.927
Experiment # 5 :	0	0	0
Experiment # 6 :	0	0	0
Experiment # 7 :	2.95	3.046	3.037
Experiment # 8 :	3.236	3.282	3.297
Experiment # 9 :	0	0	0
Experiment # 10 :	3.175	3.164	3.197
Experiment # 11 :	3.122	3.076	3.138
Experiment # 12 :	3.231	3.237	0

Experiment # 13 :

3.301	3.276	3.309

....

Experiment # 14 :

3.326	0	0

....

Experiment # 15 :

3.41	3.412	3.291

....

Experiment # 16 :

0	3.285	3.306

....

Experiment # 17 :

3.309	3.294	3.294

....

Experiment # 18 :

3.294	3.469	3.379

....

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)
A	1	23.014	23.014	15.93	21.57	17.41 %***
B	2	5.008	2.504	1.73	2.119	1.71 %
C	2	20.215	10.108	7	17.327	13.98 %***
D	2	9.223	4.611	3.19	6.334	5.11 %*
e	46	66.442	1.444		76.553	61.78 %
Total	53	123.902				100.00 %

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54 Correction Factor = 246.345
Sum (experiment values) = 115.337 Sum of sqs (experiment values) = 123.902

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	40.042	37.754	53.188	47.488	-
LEVEL 2	75.295	32.105	35.426	38.581	-
LEVEL 3	-	45.478	26.723	29.268	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	1.483	2.097	2.955	2.638	-
LEVEL 2	2.789	1.784	1.968	2.143	-
LEVEL 3	-	2.527	1.485	1.626	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	2.789
CELL DESIGN	JPL D	3	2.527
DEPOLARIZER TYPE	BCX	1	2.955
ELECTTROLYTE CONC.	0.6M	1	2.638

Total Contribution from significant factors = 10.909
Average Total for all results = 2.136
Estimate of average result (optimum) = 4.501

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
DETERMINE EFFECTS OF VARIOUS PARAMETERS ON 1A DISCHARGE AFTER 1 YEAR AT ROOM TEMPERATURE.

Procedure:
OUTPUT IS CAPACITY (IN AHRS) TO 2.0V.

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.

3 DESIGN MATRICES BUILT FOR EACH TEST CONDITION.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS (3 Trial(s) per Experiment)

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	6.69	5.02	6.63
Experiment # 2 :	0	0	7.79
Experiment # 3 :	0	0	0
Experiment # 4 :	3.14	3.52	2.48
Experiment # 5 :	0	0	0
Experiment # 6 :	0	0	0
Experiment # 7 :	5.75	6.33	6.54
Experiment # 8 :	3.67	3.68	3.57
Experiment # 9 :	0	0	0
Experiment # 10 :	10.26	9.63	10.19
Experiment # 11 :	8.25	8.13	8.35
Experiment # 12 :	12.59	12.82	0

Experiment # 13 :

11.4	11.28	11.66

....

Experiment # 14 :

10.59	0	0

....

Experiment # 15 :

12.65	12.48	12.4

....

Experiment # 16 :

0	6.59	6.64

....

Experiment # 17 :

10.16	10.34	10.1

....

Experiment # 18 :

8.49	8.62	8.49

....

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	518.32	518.32	50.47	508.05	44.27	%***
B	2	6.04	3.02	.29	0	0	%
C	2	51.58	25.79	2.51	31.04	2.71	%
D	2	99.25	49.62	4.83	78.71	6.86	%*
e	46	472.39	10.27		529.78	46.17	%
Total	53	1147.59				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54 Correction Factor = 1632.62
Sum (experiment values) = 296.92 Sum of sqs (experiment values) = 1147.59

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	64.81	106.35	123.75	120.34	-
LEVEL 2	232.11	91.6	84.63	111.76	-
LEVEL 3	-	98.97	88.54	64.82	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	2.4	5.91	6.88	6.69	-
LEVEL 2	8.6	5.09	4.7	6.21	-
LEVEL 3	-	5.5	4.92	3.6	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	8.6
CELL DESIGN	NASA149 D	1	5.91
DEPOLARIZER TYPE	BCX	1	6.88
ELECTTROLYTE CONC.	0.6M	1	6.69

Total Contribution from significant factors = 28.08
Average Total for all resuits = 5.5
Estimate of average result (optimum) = 11.58

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
DETERMINE EFFECTS OF VARIOUS PARAMETERS ON PERFROMANCE ATTRIBUTES FOR NASA APPLICATIONS.

Procedure:
OUTPUT IS % CAPACITY RETENTION UNDER 1A DISCHARGE AFTER 1 YEAR AT ROOM TEMPERATURE.

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [1 Trial(s) per Experiment]

Trial # 1

Experiment # 1 :
99.8

Experiment # 2 :
32

Experiment # 3 :
0

Experiment # 4 :
44.6

Experiment # 5 :
0

Experiment # 6 :
0

Experiment # 7 :
65.1

Experiment # 8 :
51.1

Experiment # 9 :
0

Experiment # 10 :
95.3

Experiment # 11 :
100

Experiment # 12 :
64.3

Experiment # 13 :
100

....
Experiment # 14 :
38.3

....
Experiment # 15 :
100

....
Experiment # 16 :
48.2

....
Experiment # 17 :
96.4

....
Experiment # 18 :
83.5

....

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	10435.3	10435.3	15.36	9755.8	38.33	%***
B	2	986.7	493.4	.73	0	0	%
C	2	3627	1813.5	2.67	2268	8.91	%
D	2	3609.1	1804.5	2.66	2250.1	8.84	%
e	10	6794.8	679.5		11178.9	43.92	%
Total	17	25452.9				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 18 Correction Factor = 57641.4
Sum (experiment values) = 1018.6 Sum of sqs (experiment values) = 25452.9

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	292.6	391.4	453	440.8	-
LEVEL 2	726	282.9	317.8	344.9	-
LEVEL 3	-	344.3	247.8	232.9	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	32.5	65.2	75.5	73.5	-
LEVEL 2	80.7	47.2	53	57.5	-
LEVEL 3	-	57.4	41.3	38.8	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	80.7
CELL DESIGN	NASA149 D	1	65.2
DEPOLARIZER TYPE	BCX	1	75.5
ELECTTROLYTE CONC.	0.6M	1	73.5

Total Contribution from significant factors = 294.9
Average Total for all results = 56.6
Estimate of average result (optimum) = 125.1

APPENDIX G

ANOVA REPORTS FOR 3A ROOM TEMPERATURE DISCHARGE AFTER 1 YEAR

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
DETERMINE EFFECTS OF VARIOUS PARAMETERS ON PERFROMANCE ATTRIBUTES FOR NASA APPLICATIONS.

Procedure:
OUTPUT IS 1 SEC VOLTAGE AT 3A AFTER 1 YEAR AT ROOM TEMPERTURE.

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.

3 DESIGN MATRICES BUILT FOR EACH TEST CONDITION.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	2.813	2.891	0
Experiment # 2 :	0	0	0
Experiment # 3 :	0	0	0
Experiment # 4 :	2.659	2.862	2.934
Experiment # 5 :	0	0	0
Experiment # 6 :	0	0	0
Experiment # 7 :	1.508	1.793	1.745
Experiment # 8 :	2.395	2.522	2.306
Experiment # 9 :	0	0	0
Experiment # 10 :	0	0	0
Experiment # 11 :	2.835	2.7	2.851
Experiment # 12 :	0	2.602	2.599

Experiment # 13 :

3.341	3.22	3.338

....

Experiment # 14 :

2.579	2.83	0

....

Experiment # 15 :

2.764	2.799	2.745

....

Experiment # 16 :

2.732	2.857	2.459

....

Experiment # 17 :

3.122	3.126	3.161

....

Experiment # 18 :

3.065	3.112	3.129

....

A N A L Y S I S   O F   V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)
A	1	26.094	26.094	24.75	25.04	24.51 %***
B	2	11.139	5.569	5.28	9.03	8.84 %**
C	2	5.717	2.858	2.71	3.608	3.53 %
D	2	10.69	5.345	5.07	8.581	8.4 %*
e	46	48.508	1.055		55.89	54.71 %
Total	53	102.148				100.00 %

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence   ** = 99% Confidence   *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54   Correction Factor = 151.316
Sum (experiment values) = 90.394   Sum of sqs (experiment values) = 102.148

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	26.428	19.291	37.152	40.262	-
LEVEL 2	63.966	32.071	30.427	29.452	-
LEVEL 3	-	39.032	22.815	20.68	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	.979	1.072	2.064	2.237	-
LEVEL 2	2.369	1.782	1.69	1.636	-
LEVEL 3	-	2.168	1.268	1.149	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	2.369
CELL DESIGN	JPL D	3	2.168
DEPOLARIZER TYPE	BCX	1	2.064
ELECTTROLYTE CONC.	0.6M	1	2.237

Total Contribution from significant factors = 8.838
Average Total for all results = 1.674
Estimate of average result (optimum) = 3.816

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY
Goal/Objective:
DETERMINE EFFECTS OF VARIOUS PARAMETERS ON PERFROMANCE ATTRIBUTES FOR NASA APPLICATIONS.
Procedure:
OUTPUT IS 5 SECOND VOLTAGE AT 3A AFTER 1 YEAR AT ROOM TEMPERATURE.

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.

3 DESIGN MATRICES BUILT FOR EACH TEST CONDITION.
Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	2.987	3.042	0
Experiment # 2 :	0	0	0
Experiment # 3 :	0	0	0
Experiment # 4 :	2.818	2.974	3.072
Experiment # 5 :	0	0	0
Experiment # 6 :	0	0	0
Experiment # 7 :	1.985	2.07	2.261
Experiment # 8 :	2.531	2.599	2.479
Experiment # 9 :	0	0	0
Experiment # 10 :	0	0	0
Experiment # 11 :	2.698	2.626	2.686
Experiment # 12 :	0	2.811	2.844

Experiment # 13 :
3.409 3.346 3.436

....

Experiment # 14 :
2.911 2.887 0

....

Experiment # 15 :
2.821 2.809 2.76

....

Experiment # 16 :
2.63 2.745 2.733

....

Experiment # 17 :
2.911 2.894 2.979

....

Experiment # 18 :
3.066 3.133 3.1

....

A N A L Y S I S O F V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)
A	1	23.229	23.229	20.04	22.07	20.93 %***
B	2	11.998	5.999	5.18	9.68	9.18 %**
C	2	7.313	3.657	3.15	4.995	4.74 %
D	2	9.587	4.794	4.14	7.269	6.89 %*
e	46	53.315	1.159		61.428	58.26 %
Total	53	105.442				100.00 %

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54 Correction Factor = 160.349
Sum (experiment values) = 93.053 Sum of sqs (experiment values) = 105.442

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	28.818	19.694	39.508	40.077	-
LEVEL 2	64.235	33.243	30.201	31.461	-
LEVEL 3	-	40.116	23.344	21.515	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	1.067	1.094	2.195	2.227	-
LEVEL 2	2.379	1.847	1.678	1.748	-
LEVEL 3	-	2.229	1.297	1.195	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	2.379
CELL DESIGN	JPL D	3	2.229
DEPOLARIZER TYPE	BCX	1	2.195
ELECTTROLYTE CONC.	0.6M	1	2.227

Total Contribution from significant factors =
9.03
Average Total for all results = 1.723
Estimate of average result (optimum) =
3.86

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
DETERMINE EFFECTS OF VARIOUS PARAMETERS ON PERFROMANCE ATTRIBUTES FOR NASA APPLICATIONS.

Procedure:
OUTPUT IS 60 SECOND VOLTAGE AT 3A AFTER 1 YEAR AT ROOM TEMPERATURE.

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.

3 DESIGN MATRICES BUILT FOR EACH TEST CONDITION.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	3.154	3.176	0
Experiment # 2 :	0	0	0
Experiment # 3 :	0	0	0
Experiment # 4 :	2.726	2.943	3.133
Experiment # 5 :	0	0	0
Experiment # 6 :	0	0	0
Experiment # 7 :	2.298	2.384	2.527
Experiment # 8 :	2.644	2.724	2.72
Experiment # 9 :	0	0	0
Experiment # 10 :	0	0	0
Experiment # 11 :	2.718	2.696	2.727
Experiment # 12 :	0	2.903	2.963

Experiment # 13 :

3.449	3.402	3.474

Experiment # 14 :

2.906	2.866	0

Experiment # 15 :

2.831	2.832	2.796

Experiment # 16 :

2.684	2.843	2.776

Experiment # 17 :

2.922	2.891	2.964

Experiment # 18 :

3.065	3.125	3.056

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)
A	1	21.991	21.991	17.85	20.758	18.98 %***
B	2	12.795	6.398	5.19	10.331	9.45 %**
C	2	8.491	4.245	3.45	6.026	5.51 %*
D	2	9.413	4.706	3.82	6.948	6.35 %*
e	46	56.684	1.232		65.309	59.71 %
Total	53	109.373				100.00 %

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54 Correction Factor = 168.25
Sum (experiment values) = 95.318 Sum of sqs (experiment values) = 109.373

R E S P O N S E   T A B L E

Factor:	A	B	C	D	-
LEVEL 1	30.429	20.337	40.969	40.509	-
LEVEL 2	64.889	33.358	30.778	32.646	-
LEVEL 3	-	41.623	23.571	22.163	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

R E S P O N S E   T A B L E   (A V E R A G E S)

Factor:	A	B	C	D	-
LEVEL 1	1.127	1.13	2.276	2.251	-
LEVEL 2	2.403	1.853	1.71	1.814	-
LEVEL 3	-	2.312	1.31	1.231	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

M A I N   E F F E C T S   A N A L Y S I S

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	2.403
CELL DESIGN	JPL D	3	2.312
DEPOLARIZER TYPE	BCX	1	2.276
ELECTTROLYTE CONC.	0.6M	1	2.251

Total Contribution from significant factors =
9.242
Average Total for all results = 1.765
Estimate of average result (optimum) =
3.947

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
DETERMINE EFFECTS OF VARIOUS PARAMETERS ON PERFROMANCE ATTRIBUTES FOR NASA APPLICATIONS.

Procedure:
OUTPUT IS VOLTAGE AT 50% DOD AT 3A AFTER 1 YEAR AT ROOM TEMPERATURE

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.

3 DESIGN MATRICES BUILT FOR EACH TEST CONDITION.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	2.875	2.879	0
Experiment # 2 :	0	0	0
Experiment # 3 :	0	0	0
Experiment # 4 :	2.77	2.79	2.79
Experiment # 5 :	0	0	0
Experiment # 6 :	0	0	0
Experiment # 7 :	2.502	2.309	2.635
Experiment # 8 :	3.14	3.16	2.152
Experiment # 9 :	0	0	0
Experiment # 10 :	0	0	0
Experiment # 11 :	2.86	2.89	2.85
Experiment # 12 :	0	3.166	3.151

Experiment # 13 :

3.2	3.118	3.182

....

Experiment # 14 :

2.552	2.497	0

....

Experiment # 15 :

3.114	3.115	3.114

....

Experiment # 16 :

2.793	2.882	2.691

....

Experiment # 17 :

3.166	3.131	3.155

....

Experiment # 18 :

3.287	3.34	3.317

....

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	24.765	24.765	19.93	23.522	20.87	%***
B	2	14.681	7.34	5.91	12.196	10.82	%**
C	2	5.333	2.667	2.15	2.848	2.53	%
D	2	10.792	5.396	4.34	8.307	7.37	%*
e	46	57.156	1.243		65.854	58.42	%
Total	53	112.726				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54 Correction Factor = 172.71
Sum (experiment values) = 96.573 Sum of sqs (experiment values) = 112.726

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	30.002	20.671	39.416	41.499	-
LEVEL 2	66.571	32.242	31.553	33.207	-
LEVEL 3	-	43.66	25.604	21.867	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	1.111	1.148	2.19	2.306	-
LEVEL 2	2.466	1.791	1.753	1.845	-
LEVEL 3	-	2.426	1.422	1.215	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	2.466
CELL DESIGN	JPL D	3	2.426
DEPOLARIZER TYPE	BCX	1	2.19
ELECTTROLYTE CONC.	0.6M	1	2.306

Total Contribution from significant factors =
9.388
Average Total for all results = 1.788
Estimate of average result (optimum) =
4.023

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY
Goal/Objective:
DETERMINE EFFECTS OF VARIOUS PARAMETERS ON PERFROMANCE ATTRIBUTES FOR NASA APPLICATIONS.
Procedure:
OUTPUT IS CAPACITY TO 2.0V AT 3A AFTER 1 YEAR AT ROOM TEMPERATURE.

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.

3 DESIGN MATRICES BUILT FOR EACH TEST CONDITION.
Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	1.99	2.04	0
Experiment # 2 :	0	0	0
Experiment # 3 :	0	0	0
Experiment # 4 :	2.07	1.28	1.84
Experiment # 5 :	0	0	0
Experiment # 6 :	0	0	0
Experiment # 7 :	5.97	6.6	6.78
Experiment # 8 :	8.35	8.51	8.55
Experiment # 9 :	0	0	0
Experiment # 10 :	0	0	0
Experiment # 11 :	3.53	3.21	3.4
Experiment # 12 :	0	10.17	10.17

Experiment # 13 :

7.6	7.43	8.03

....

Experiment # 14 :

10.75	10.9	0

....

Experiment # 15 :

8.6	9.32	10.04

....

Experiment # 16 :

5.88	5.78	5.84

....

Experiment # 17 :

9.46	9.73	9.59

....

Experiment # 18 :

8.87	8.56	8.61

....

A N A L Y S I S   O F   V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	273.33	273.33	30.34	264.32	29.31	%***
B	2	189.54	94.77	10.52	171.53	19.02	%***
C	2	8.27	4.13	.46	0	0	%
D	2	16.32	8.16	.91	0	0	%
e	46	414.36	9.01		465.98	51.67	%
Total	53	901.82				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence   ** = 99% Confidence   *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY

Number of experiments = 54   Correction Factor = 974.95

Sum (experiment values) = 229.45   Sum of sqs (experiment values) = 901.82

R E S P O N S E   T A B L E

Factor:	A	B	C	D	-
LEVEL 1	53.98	34.51	69.13	76.1	-
LEVEL 2	175.47	77.86	85.98	88.79	-
LEVEL 3	-	117.08	74.34	64.56	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

R E S P O N S E   T A B L E   (A V E R A G E S)

Factor:	A	B	C	D	-
LEVEL 1	2	1.92	3.84	4.23	-
LEVEL 2	6.5	4.33	4.78	4.93	-
LEVEL 3	-	6.5	4.13	3.59	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

M A I N   E F F E C T S   A N A L Y S I S

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	6.5
CELL DESIGN	JPL D	3	6.5
DEPOLARIZER TYPE	TC	2	4.78
ELECTTROLYTE CONC.	1.2M	2	4.93

Total Contribution from significant factors =
22.71
Average Total for all results = 4.25
Estimate of average result (optimum) =
9.96

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
DETERMINE EFFECTS OF VARIOUS PARAMETERS ON PERFROMANCE ATTRIBUTES FOR NASA APPLICATIONS.

Procedure:
OUTPUT IA % CAPACITY RETENTION UNDER 3A DISCHARGE AFTER 1 YEAR AT ROOM TEMPERATURE.

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [1 Trial(s) per Experiment]

Trial # 1

Experiment # 1 :
58

Experiment # 2 :
0

Experiment # 3 :
0

Experiment # 4 :
33.6

Experiment # 5 :
0

Experiment # 6 :
0

Experiment # 7 :
88.5

Experiment # 8 :
90

Experiment # 9 :
0

Experiment # 10 :
0

Experiment # 11 :
97.1

Experiment # 12 :
67.5

Experiment # 13 :
95.1

....
Experiment # 14 :
62.6

....
Experiment # 15 :
100

....
Experiment # 16 :
64.2

....
Experiment # 17 :
97.9

....
Experiment # 18 :
85.9

....

A N A L Y S I S   O F   V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)
A	1	8897.8	8897.8	6.64	7558.5	25.77 %*
B	2	3587.4	1793.7	1.34	908.9	3.1 %
C	2	907.6	453.8	.34	0	0 %
D	2	2541.1	1270.6	.95	0	0 %
e	10	13392.9	1339.3		20859.5	71.13 %
Total	17	29326.8				100.00 %

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence   ** = 99% Confidence   *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 18   Correction Factor = 49130.7
Sum (experiment values) = 940.4   Sum of sqs (experiment values) = 29326.8

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	270.1	222.6	339.4	386.6	-
LEVEL 2	670.3	291.3	347.6	337	-
LEVEL 3	-	426.5	253.4	216.8	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	30	37.1	56.6	64.4	-
LEVEL 2	74.5	48.6	57.9	56.2	-
LEVEL 3	-	71.1	42.2	36.1	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	74.5
CELL DESIGN	JPL D	3	71.1
DEPOLARIZER TYPE	TC	2	57.9
ELECTTROLYTE CONC.	0.6M	1	64.4

Total Contribution from significant factors = 267.9
Average Total for all results = 52.2
Estimate of average result (optimum) = 111.2

APPENDIX H

ANOVA REPORTS FOR MICROCALORIMETRY DATA

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY
Goal/Objective:
TEST 4: MICROCALORIMETRY. OUTPUT IS FRESH SELF-DISCHARGE CURRENT (μAmps)
Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.
Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   (3 Trial(s) per Experiment)

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	181.56	192.86	271.73
Experiment # 2 :	218.88	76.13	68.08
Experiment # 3 :	58.47	37.28	46.55
Experiment # 4 :	407.03	511.25	466.48
Experiment # 5 :	102.43	94.51	82.09
Experiment # 6 :	33.32	39.44	42.22
Experiment # 7 :	1376.45	562.06	365.34
Experiment # 8 :	219.3	231.12	184.87
Experiment # 9 :	226.26	126.49	128.15
Experiment # 10 :	189.22	244.52	158.89
Experiment # 11 :	38.39	37.26	26.31
Experiment # 12 :	77.38	51.34	103.54
Experiment # 13 :	191.16	181.29	158.09
Experiment # 14 :			

196.97 168.85 127.06

....

Experiment # 15 :

133.18 112.02 87.36

....

Experiment # 16 :

929.29 936.46 732.77

....

Experiment # 17 :

98.13 73.86 70.94

....

Experiment # 18 :

191.99 184.36 224.97

....

A N A L Y S I S   O F   V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	7228.01	7228.01	.24	0	0	%
B	2	701944.49	350972.25	11.52	641026.11	18.18	%***
C	2	1355404.72	677702.36	22.25	1294486.34	36.71	%***
D	2	60222.22	30111.11	.99	0	0	%
e	46	1401122.69	30459.19		1590409.68	45.11	%
Total	53	3525922.13				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence   ** = 99% Confidence   *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54   Correction Factor = 2700529.04
Sum (experiment values) = 12075.95   Sum of sqs (experiment values) = 3525922.13

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	6350.35	2078.39	8056.45	3189.26	-
LEVEL 2	5725.6	3134.75	2115.18	4310.09	-
LEVEL 3	-	6862.81	1904.32	4576.6	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	235.2	115.47	447.58	177.18	-
LEVEL 2	212.06	174.15	117.51	239.45	-
LEVEL 3	-	381.27	105.8	254.26	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the smaller the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	212.06
CELL DESIGN	NASA149 D	1	115.47
DEPOLARIZER TYPE	CSC	3	105.8
ELECTTROLYTE CONC.	0.6M	1	177.18

Total Contribution from significant factors =
610.51
Average Total for all results = 223.63
Estimate of average result (optimum) =
-60.38

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
TEST 4: MICROCALORIMETRY. OUTPUT IS 2ND MICROCAL DATA IN µA.

Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	161.45	172.9	236.44
Experiment # 2 :	57.17	49.98	48.28
Experiment # 3 :	45.02	45.79	45.02
Experiment # 4 :	395.54	380.54	379.75
Experiment # 5 :	64.47	61.9	66.99
Experiment # 6 :	20.03	38.66	19.65
Experiment # 7 :	303.78	150.66	119.93
Experiment # 8 :	230.56	220.21	200.21
Experiment # 9 :	161.36	110.06	114.66
Experiment # 10 :	78.69	79.45	85.6
Experiment # 11 :	22.12	16.15	16.44
Experiment # 12 :	39.42	49.4	63.36
Experiment # 13 :	137.3	103.3	116.15
Experiment # 14 :			

91.67 78.32 82.86

....

Experiment # 15 :
69.94 53.46 53.25

....

Experiment # 16 :
672.06 398.92 310.43

....

Experiment # 17 :
43.42 35.33 55.96

....

Experiment # 18 :
210.31 199.26 226.34

....

A N A L Y S I S   O F   V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	4856.42	4856.42	.56	0	0	%
B	2	170737.26	85368.63	9.77	153255.18	17.47	%***
C	2	286528.26	143264.13	16.39	269046.18	30.68	%***
D	2	12860.3	6430.15	.74	0	0	%
e	46	402087.71	8741.04		454768.58	51.85	%
Total	53	877069.94				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence   ** = 99% Confidence   *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54
Sum (experiment values) = 7289.92
Correction Factor = 984128.4
Sum of sqs (experiment values) = 877069.94

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	3901.01	1312.68	4282.89	2478.77	-
LEVEL 2	3388.91	2213.78	1442.04	2068	-
LEVEL 3	-	3763.46	1564.99	2743.15	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	144.48	72.93	237.94	137.71	-
LEVEL 2	125.52	122.99	80.11	114.89	-
LEVEL 3	-	209.08	86.94	152.4	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the smaller the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	125.52
CELL DESIGN	NASA149 D	1	72.93
DEPOLARIZER TYPE	TC	2	80.11
ELECTTROLYTE CONC.	1.2M	2	114.89

Total Contribution from significant factors = 393.45
Average Total for all results = 135
Estimate of average result (optimum) = -11.55

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY
Goal/Objective:
TEST 4: MICROCALORIMETRY. OUTPUT IS 3RD MICROCAL DATA IN µA.
Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.
Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	169.74	177.43	263.11
Experiment # 2 :	49.58	34.37	38.19
Experiment # 3 :	45.72	31.28	35.14
Experiment # 4 :	280.15	220.23	270.55
Experiment # 5 :	54.01	61.09	70.56
Experiment # 6 :	19.72	31.68	20.84
Experiment # 7 :	281.83	156.84	106.49
Experiment # 8 :	318.44	388.7	243.06
Experiment # 9 :	159	116.25	105.19
Experiment # 10 :	55.92	104.98	55.26
Experiment # 11 :	14.02	20.77	24.3
Experiment # 12 :	51.93	51.68	71.37
Experiment # 13 :	141.48	108.88	97.22
Experiment # 14 :			

74.47 72.91 71.16

....

Experiment # 15 :

42.36 44.57 49.54

....

Experiment # 16 :

145.92 147.52 138.11

....

Experiment # 17 :

29.01 25.85 35.53

....

Experiment # 18 :

193.84 192.85 219.91

....

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	39898.61	39898.61	7.69	34707.53	7.96	%**
B	2	87658.01	43829	8.44	77275.85	17.71	%***
C	2	69801.7	34900.85	6.72	59419.54	13.62	%***
D	2	126.39	63.2	.01	0	0	%
e	46	238789.68	5191.08		264871.47	60.71	%
Total	53	436274.38				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence   ** = 99% Confidence   *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54   Correction Factor = 673472.84
Sum (experiment values) = 6030.55   Sum of sqs (experiment values) = 436274.38

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	3749.19	1294.79	2921.66	2047.6	-
LEVEL 2	2281.36	1731.42	1626.02	1982.12	-
LEVEL 3	-	3004.34	1482.87	2000.83	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	138.86	71.93	162.31	113.76	-
LEVEL 2	84.49	96.19	90.33	110.12	-
LEVEL 3	-	166.91	82.38	111.16	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the smaller the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	84.49
CELL DESIGN	NASA149 D	1	71.93
DEPOLARIZER TYPE	CSC	3	82.38
ELECTTROLYTE CONC.	1.2M	2	110.12

Total Contribution from significant factors = 348.92
Average Total for all results = 111.68
Estimate of average result (optimum) = 13.89

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
DETERMINE EFFECTS OF VARIOUS PARAMETERS ON PERFROMANCE ATTRIBUTES FOR NASA APPLICATIONS.

Procedure:
OUTPUT IS 4TH MICROCAL DATA IN µA.

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.

3 DESIGN MATRICES BUILT FOR EACH TEST CONDITION.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	179.36	193.39	175.55
Experiment # 2 :	50.95	42.52	50.17
Experiment # 3 :	42.92	27.25	34.15
Experiment # 4 :	139.4	132.12	199.17
Experiment # 5 :	56.97	73.94	71.15
Experiment # 6 :	17.94	24.88	16.29
Experiment # 7 :	275.45	173.75	155.73
Experiment # 8 :	386.46	426.47	297.35
Experiment # 9 :	145.73	110.26	104.44
Experiment # 10 :	36.4	148.02	41.59
Experiment # 11 :	24.88	21.21	24.96
Experiment # 12 :	62.4	70.65	65.16

Experiment # 13 :

149.14	114.94	112.6

....

Experiment # 14 :

68.04	51.39	63.48

....

Experiment # 15 :

47.07	42.48	41.77

....

Experiment # 16 :

62.01	46.93	66.04

....

Experiment # 17 :

29.28	23.47	39.89

....

Experiment # 18 :

171.76	170.34	155.51

....

					ANALYSIS OF VARIATION	
Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)
A	1	50560.38	50560.38	8.96	44915.64	10.53 %***
B	2	82012.7	41006.35	7.26	70723.22	16.58 %***
C	2	30860.68	15430.34	2.73	19571.2	4.59 %
D	2	3380.43	1690.22	.3	0	0 %
e	46	259658.08	5644.74		291262.22	68.3 %
Total	53	426472.28				100.00 %

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54
Sum (experiment values) = 5555.17
Correction Factor = 571479.88
Sum of sqs (experiment values) = 426472.28

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	3603.76	1291.53	2401.59	1674.43	-
LEVEL 2	1951.41	1422.77	1802.58	2023.13	-
LEVEL 3	-	2840.87	1351	1857.61	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	133.47	71.75	133.42	93.02	-
LEVEL 2	72.27	79.04	100.14	112.4	-
LEVEL 3	-	157.83	75.06	103.2	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the smaller the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	72.27
CELL DESIGN	NASA149 D	1	71.75
DEPOLARIZER TYPE	CSC	3	75.06
ELECTTROLYTE CONC.	0.6M	1	93.02

Total Contribution from significant factors =
312.1
Average Total for all results = 102.87
Estimate of average result (optimum) =
3.48

APPENDIX I

SHORT CIRCUIT TEST PROCEDURE FROM HAZARD DEFINITION STUDY

INTRODUCTION:

Li/BCX cells are extensively used in space applications primarily because this system offers improved safety over others such as Li/$SOCl_2$ [1,2]. In addition, these cells, with an open circuit voltage of 3.90 V, display improved low temperature discharge behavior. The intent of the Hazard Definition study, Modification 5, NAS 9-18395, is to obtain accurate thermal information for the Li/BCX system configured as 'C', 'D' (universal design) and 'DD' cells. Results obtained are to be compared with the current JPL $SOCl_2$ 'D' (JPL TC D) cell.

BACKGROUND:

As space exploration continues to expand, applications require larger, higher energy batteries. In order to fulfill requirements, a complete understanding of the thermal behavior of applicable cells is necessary. The intention of the Hazard Definition study is to provide information related to heat transfer profiles from the cells that will be used for the development of the survival radio and EMU-PLSS batteries. The survival radio battery utilizes three BCX II C cells while the EMU-PLSS is designed to accommodate 18 BCX II DD cells encased in an aluminum housing.

In addition to the BCX II C and DD cells, the universal BCX I D and the JPL TC D cells were studied. Two BCX chemistries exist: BCX I and BCX II. The BCX II chemistry, compared to BCX I, offers improved restart performance after partial discharge [3], improved shelf life (particularly at elevated temperature) and facilitates cell fabrication. The NASA "D Cell" study, Modification 10, NAS 9-18395, is currently in progress. The intent of this latter study is to identify the configuration providing optimum performance for future space applications. Eighteen configurations representing cell design, electrolyte salt, concentration and depolarizer are included. The study focuses on rate capability, heat output under varying short circuit conditions, cell microcalorimetry and shelf life.

EXPERIMENTAL PROCEDURES:

The maximum short circuit resistance for each cell model was chosen based on the maximum rated operating current for that model. The minimum short circuit resistance for each cell model was chosen based on the results of preliminary short circuit tests performed on prototype cells and represents the lowest possible resistance through which the cell can be consistently shorted without resulting in a vent, rupture or open circuit. The seven test loads used for each cell model are shown below:

CELL MODEL	TEST LOADS (OHMS)
BCX II C	0.325, 0.50, 1.00, 2.00, 3.00, 4.00, 6.00
BCX II DD	0.325, 0.40, 0.50, 0.60, 0.70, 0.85, 1.00
BCX I D	0.325, 0.40, 0.50, 0.70, 1.00, 2.00, 3.00
JPL TC D	0.200, 0.325, 0.40, 0.60, 0.70, 0.85, 1.00

Based on the initial smart short-circuit tests of the BCX II DD cells, a minimum load of 0.175 ohms was chosen. The minimum test load was later increased to 0.325 ohms after the 0.175 Ω load caused several cells to lose continuity. The difference between the initial short-circuit test cells and the actual Hazard Definition test cells can be attributed to a minor design change.

The method of test used was a constant resistance discharge within a liquid-filled calorimeter. The calorimeter was a 4 liter insulated, nalgene plastic container which was rated for use from -40 to 100°C.
Silicone oil was used as the heat sinking medium. The silicone oil chosen was electrically insulative and had a specific heat in the desired range.
The silicone oil was obtained from Aldrich Chemical Company (#14,615-3).
A list of the oil's physical properties (as reported by Aldrich) can be found in Table 1. The silicone oil test fluid was circulated by a low RPM stirrer with non-conductive shaft and blades. The stirrer ensured a homogeneous temperature throughout the oil bath. This test apparatus was chosen due to its simplicity and versatility. The temperature rise of the heat sinking medium could easily be adjusted simply by changing the volume of the fluid

(C and D size cells were run with 2 liters of oil while DD cells were run with 3 liters of oil). This allowed all four cell models to be tested using the same basic test set-up.

The cells were shorted through precision (±0.1%), 100 watt resistors rather than heater wire as specified in the SOW paragraph 3.3. The resistors were chosen because of their resistive stability over the expected temperature and current range. The stability of the resistive load was critical since all electrical performance calculations were based on the measured voltages and the known, fixed circuit resistance.

A Field Effect Transistor (FET) based circuit was used to complete the short circuit required to perform the test. This method was chosen for its low resistance (0.010Ω), submersibility, and high reliability. In addition, coupling with an opto-isolator allowed the circuit to be controlled remotely by the data acquisition system.

Cell temperatures were recorded using three Type T thermocouples on each cell. The thermocouples were evenly spaced along the side of each cell and were attached using a thermally conductive, aluminum-based epoxy (Devcon P/N 10610). Oil temperatures were measured using three glass-encapsulated thermistor probes submerged within the oil bath. During a test the oil temperature typically lagged the cell temperature by only 2 to 4°C, indicating that the circulating oil effectively removed heat from the cell.

The data acquisition system consisted of a Macintosh II with a National Instruments NBM1016 I/O board and a LabView 2.0 software package. The acquisition system recorded data from all thermocouples and thermistors as well as cell and circuit voltages.

In addition, the Macintosh system supplied the actuation signal for the load application circuit, thus allowing for automatic operation.

The cell under test, precision resistor and FET circuit were all completely submerged in the calorimeter oil bath during a test. Diagrams of the test setup are shown in Figures 1 and 2. The calorimeter test procedure and the acquisition program user instructions can be found in Appendix 3. Prior to performing a test, the cell and precision resistor were connected to the test

circuit. The entire circuit (cell, resistor and FET) was then submerged in the oil bath. The stirrer was started and the system was allowed to stabilize for several hours at ambient temperature. After stabilization, the test was started and the cell was allowed to discharge until the pre-determined end-of-test (EOT) criterion was met. The SOW states that the EOT shall be defined as a cell voltage of 0.0 volts. It was determined however, that at low voltage (current) levels, the rate of energy loss from the calorimeter exceeded the energy output rate of the circuit, and the test fluid began to cool rapidly. This resulted in a net loss in measured energy, even though the circuit was still producing a small amount of heat. It was determined that a circuit current of 0.10 amps was a more practical EOT criteria. The determination of the EOT criteria is summarized in RER 92/089, which can be found in Appendix 4.

SYSTEM CALIBRATION:

Due to the differences in heat capacities and test fluid volumes for the three cell sizes tested (C, D and DD), a separate calibration of the test system was performed for each cell size. The calibration tests were performed by replacing the cell with a D.C. power supply in the discharge circuit (the power supply was outside of the system). Note that even though the cell was removed from the circuit, it was left in the calorimeter as a source of heat sinking. The only significant source of energy input for the calorimeter then, was produced by the known voltage passing through the known resistance of the discharge circuit.

The total energy output of the circuit (therefore the energy input for the calorimeter) could then be calculated using the following equation:

$$\text{Theoretical Energy} = \int (V^2 / R)\, dt$$

For calculation purposes this can be approximated by:

$$\#1)\quad \text{Theoretical Energy} = \Sigma_t [\, (V^2 / R) * \Delta t \,]$$

where: V is the power supply voltage
R is the fixed circuit resistance
Δt is the elapsed time in seconds

The measured energy was calculated based on the temperature rise of the test fluid using the following equation:

$$\#2)\quad \text{Measured Energy} = \Sigma_t [\, \Delta T * C_p * m \,]$$

where: ΔT is the change in fluid temperature
C_p is the specific heat of the fluid
m is the mass of the fluid

Several tests were run for each cell size using different power supply voltages (therefore different currents) for each test. The theoretical energy for each calibration test was then compared to the measured energy. The difference between the two quantities was the "energy loss" of the calorimeter. This energy loss includes the energy required to heat the cell, electronic components and the calorimeter itself, as well as the heat energy lost to the atmosphere through the calorimeter boundary. Note that a separate calibration was required for each cell size due to changes in both the cell specific heat and the test fluid volume.

It was determined that the average rate of energy loss (K) was a function of both the difference between oil and ambient temperatures (ΔT) and the length of the test (t). That is to say $K = f(\Delta T, t)$.

It was noted that the rate of energy loss was greater at the beginning of a test because of the energy required to heat the cell, resistor, circuit and calorimeter during this period of rapid temperature change. As the test progressed, the rate of temperature change decreased along with the rate of energy loss. Thus, for a given ΔT, the time average rate of energy loss was greater for short duration tests.

To make the final energy calculations as straightforward as possible, an attempt was made to express the energy loss term (K) as a constant for each test with a known average ΔT and duration (t). K then represents the *time average* energy loss rate for a given test (in calories/hour). For each cell size the "energy loss" data was plotted and a "best-fit" curve was generated. The calibration plots and equations are shown in Figure 3. Note that the average rate of energy loss (calories/hour) was plotted as a function of ΔT/hour, which is the average difference between oil and ambient temperatures divided by the total test time. The relation between ΔT/hour and the average energy loss rate was logarithmic. The calibration curves (and equations) were used to determine the average rate of energy loss, or the "calibration factor" (K), for each test. This simplified method of accounting for energy loss worked very well in practice.

CELL AND CIRCUIT ENERGY CALCULATIONS:

The theoretical energy dissipated by the cell (in the form of heat) was calculated for each test using the following equation:

$$\text{Theoretical Cell Energy} = \int [\, R_{cell} * I^2 \,]\, dt$$

Replacing $[R_{cell}]$ with $[(V_{OC} - V_{CC}) / I\,]$, leads to the following equation:

$$\text{Theoretical Cell Energy} = \int [\, (V_{OC} - V_{CC}) * (I) \,]\, dt$$

For calculation purposes this can be approximated by:

$$\#3)\quad \text{Theoretical Cell Energy} = \Sigma_t [\, (V_{OC} - V_{CC}) * (I) * (\Delta t) \,]$$

where: V_{OC} is the cell open-circuit voltage
V_{CC} is the cell closed-circuit voltage

I is the circuit current
Δt is the elapsed time in seconds

The theoretical energy dissipated by the circuit (resistor and FET) was calculated for each test using the following equation:

$$\text{Theoretical Circuit Energy} = \int [(I)^2 * (R_C)] \, dt$$

For calculation purposes this can be approximated by:

$$\#4) \quad \text{Theoretical Circuit Energy} = \Sigma_t [(I)^2 * (R_C) * (\Delta t)]$$

where: I is the circuit current
R_C is the total circuit resistance (resistor and FET)
Δt is the elapsed time in seconds

The total theoretical energy (heat) output of the cell and circuit was then found by adding equations #3 and #4.

The total measured energy, based on the temperature increase of the oil, was calculated using the following equation:

$$\#5) \quad \text{Total Measured Energy} = \Sigma_t [(\Delta T) * (C_p) * (m) + K]$$

where: ΔT is the change in oil temperature
C_p is the specific heat of the oil
m is the mass of the oil
K is the calculated heat loss of the calorimeter (Ref: Figure 3)

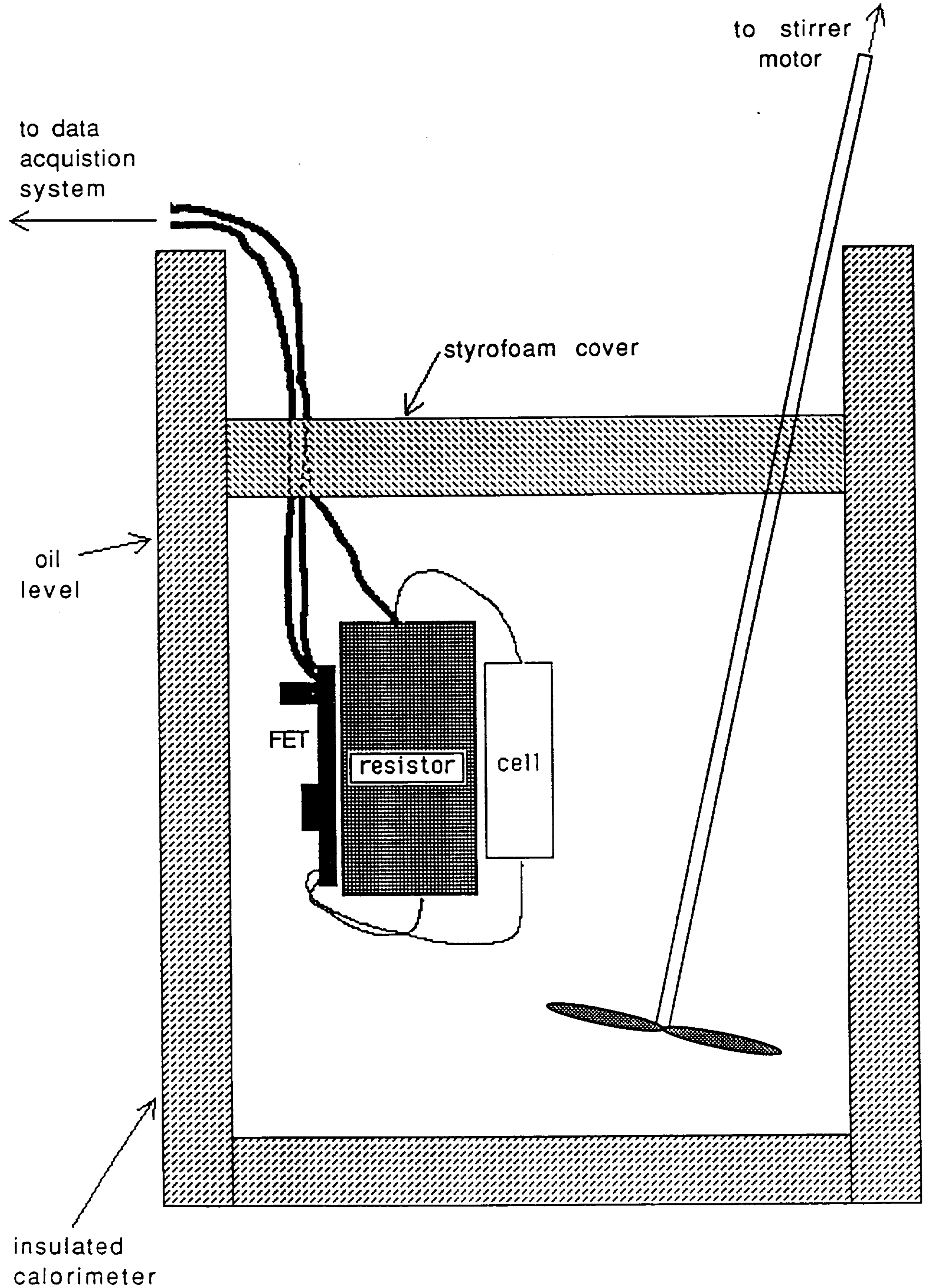
Note that the beginning-of-life open-circuit voltage (OCV) of each cell was used in the calculation of theoretical cell energy (Ref: equation #3). The use of other values was investigated prior to deciding on the use of OCV. One such value was thermoneutral potential. A thermoneutral potential of 4.14 volts was used for the BCX DD cells [4]. The use of thermoneutral potential in place of OCV resulted in an increase in *total* theoretical energy of

approximately 5 percent. Several trials were also run using 3.6 volts in place of OCV (for BCX II cells). It was thought that the use of 3.6 volts may yield better results than the use of beginning-of-life OCV since the OCV of BCX II cells drops to 3.6 volts after approximately 15% of the capacity is removed from the cell. Substitution of 3.6 volts in equation #3 resulted in a decrease in *total* theoretical energy of approximately 8 percent. Overall, the use of beginning-of-life OCV resulted in the best correlation between theoretical energy and measured energy.

PHYSICAL PROPERTIES OF ALDRICH #14,615-3 OIL

PHYSICAL PROPERTY	VALUE
NOMINAL VISCOSITY (cSt)	50
VISCOSITY TEMPERATURE COEFFICIENT	0.59
SPECIFIC GRAVITY	0.963
FLASH POINT (°F)	600
THERMAL EXPANSION (cc/cc/°C)	0.00106
THERMAL CONDUCTIVITY (BTU/hr ft °F)	0.087
SPECIFIC HEAT (cal/g °C)	0.36
DIELECTRIC STRENGTH (kV)	35
VOLUME RESISTIVITY (Ω-cm)	1 x 10EE14

TABLE 1



to stirrer
motor
to data
acquistion
system
styrofoam cover
oil
level
FET
resistor
cell
insulated
calorimeter

FIGURE 1

CALORIMETER CIRCUIT DIAGRAM

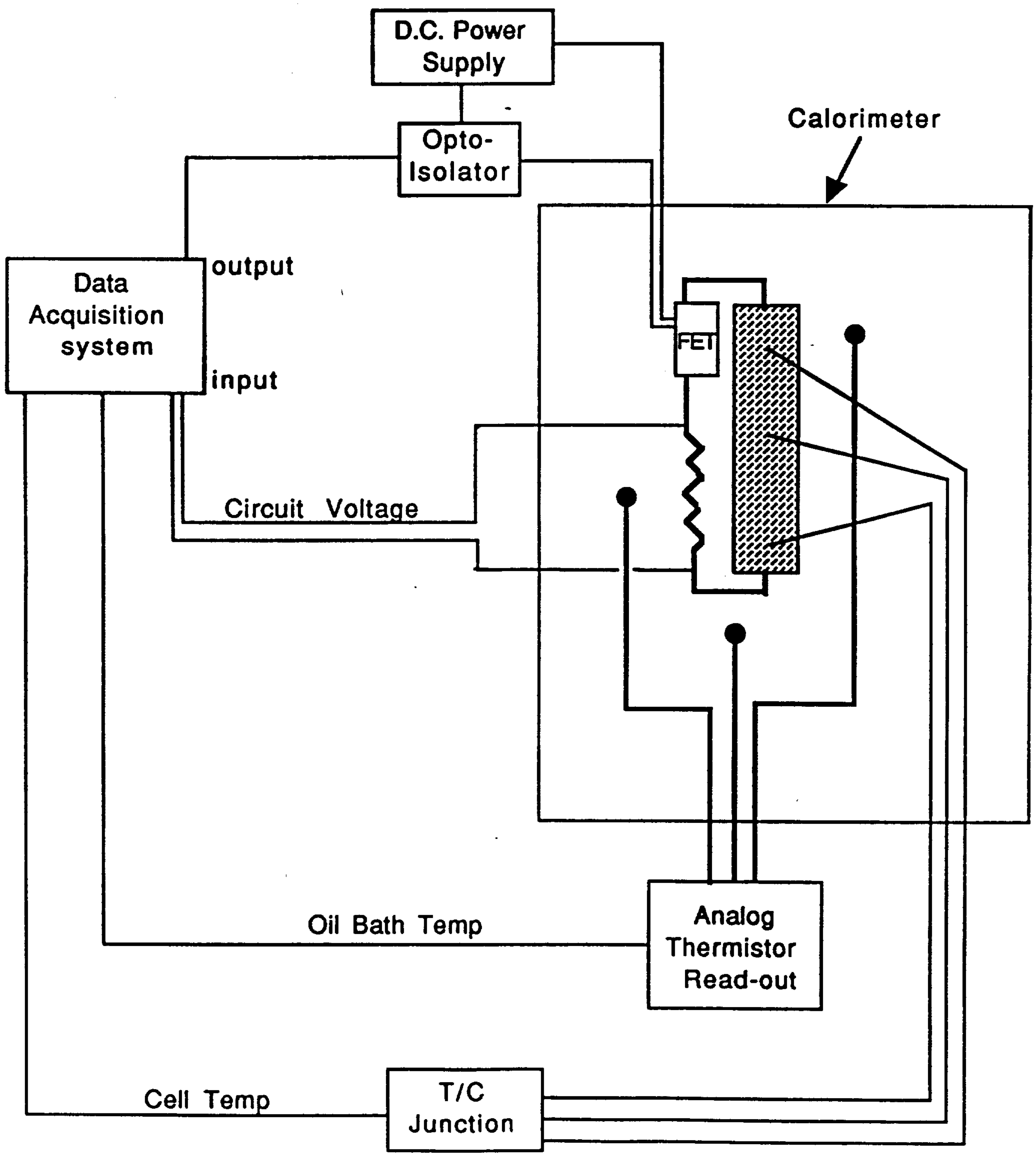
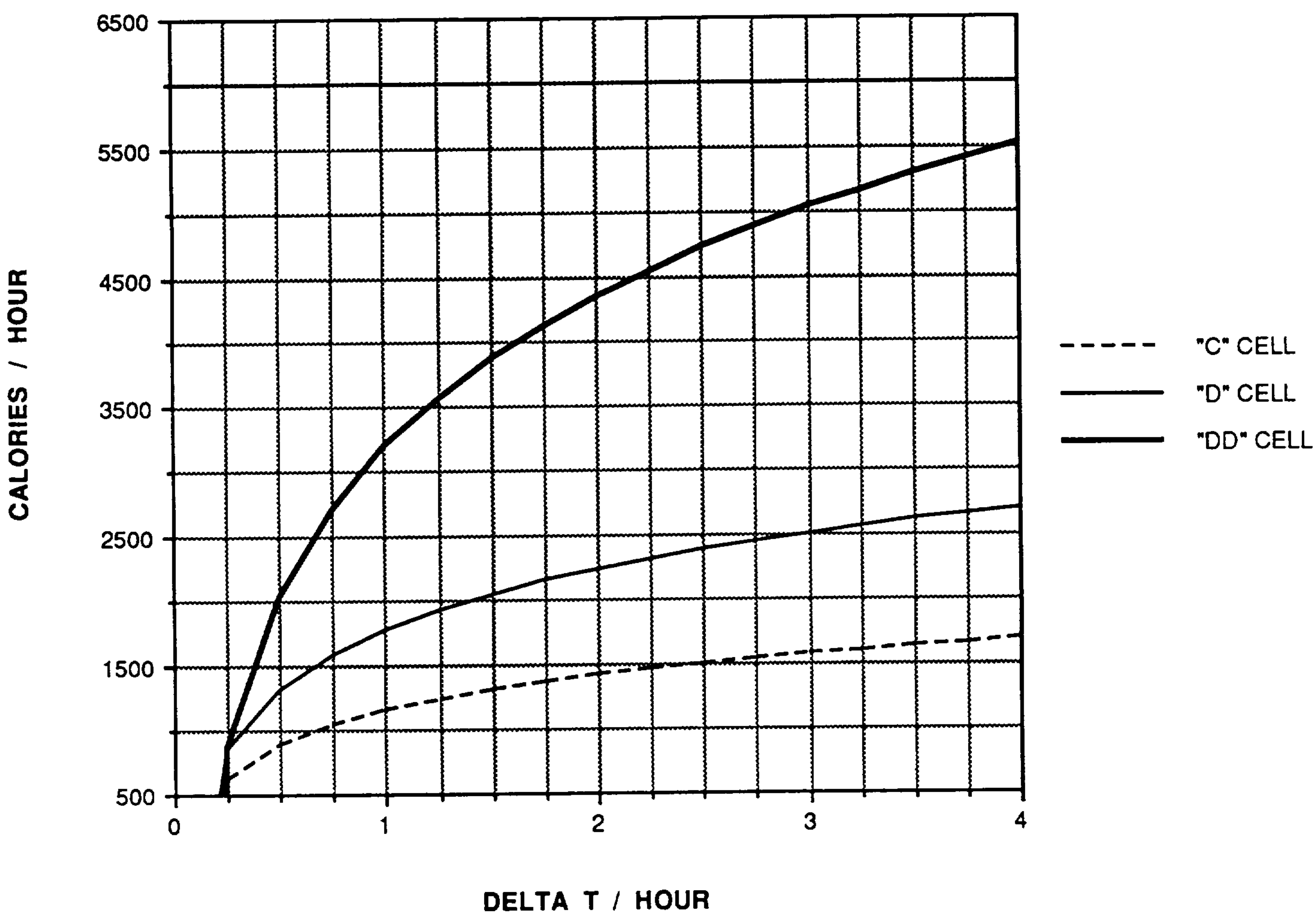


FIGURE 2

CALORIMETER ENERGY LOSS (CALIBRATION) CURVES



CALIBRATION EQUATIONS

C CELLS: $y = 896.8 \, \mathrm{LOG}(x) + 1146$

D CELLS: $y = 1532.0 \, \mathrm{LOG}(x) + 1776$

DD CELLS: $y = 3866.1 \, \mathrm{LOG}(x) + 3184$

FIGURE 3

APPENDIX J

RELIABILITY REPORT #92-066
1A FOD WITHOUT BYPASS DIODES

WG

RELIABILITY TEST RESULTS

MODEL: D (VARIOUS CHEMISTRIES)	DATE: 08 MAY 1992	REPORT NO: 92-066

TEST: CONSTANT CURRENT FORCE OVERDISCHARGE W/O DIODES

ORIGINATOR: P. Size (Refer E•ITR92-019)

PURPOSE: The purpose of this test is to satisfy the requirements as stated in the NASA Contract NAS9-18395 para. 9.2.2.

PARAMETERS: Fifty-three cells of various constructions and chemistries were submitted for test. **NOTE:** One cell vented during the previous test and was unavailable for this test. The cells were one ampere constant current force overdischarged at room temperature for a minimum of sixteen hours in voltage reversal with a maximum preset voltage push of 38 volts. The cells were not protected with by-pass diodes. Voltage, current, and skin temperature were monitored and recorded. **NOTE:** These cells were previously tested as stated above but were equipped with protective shunt diodes. This information is documented on RTR92-035.

TEST RESULTS: Refer attachments (Tables 1-6)

SUBMITTED BY: Thomas L. Wnight	DATE: 11 May 92
PPROVED BY: Dough D Elvert	DATE: 14 May 92
DISTRIBUTION: P. SIZE	PAGE: 1 OF 7

FORM NO. 7044/0783 "REV A"

TEST REQUEST: E•ITR92-019

0NE AMPERE FORCE OVERDISCHARGE

COMMERCIAL
MEDICAL
* OTHER (R&D EXP.)

PERFORMED BY: L.P., S.B.

CHEMISTRY: VARIOUS

SERIAL NUMBER	MODEL	GROUP #	OCV BEFORE TEST	COMMENT	TIME IN VOLTAGE REVERSAL (HR:MIN)	PEAK TEMP. (°C)	TIME TO PEAK TEMP. (HR:MIN)	RESULTS
69171	NASA	1	0.00	COULD NOT CARRY CURRENT	21:57	*	N/A	NO PHYSICAL CHANGE
69177	NASA	1	0.01	COULD NOT CARRY CURRENT	16:29	*	N/A	NO PHYSICAL CHANGE
69185	NASA	1	0.00	COULD NOT CARRY CURRENT	16:40	*	N/A	NO PHYSICAL CHANGE
69204	NASA	2	3.56	CARRIED 1A FOR ENTIRE TEST	22:01	*	N/A	NO PHYSICAL CHANGE
69211	NASA	2	3.61	CARRIED 1A FOR ENTIRE TEST	16:38	*	N/A	NO PHYSICAL CHANGE
69215	NASA	2	3.55	CARRIED 1A FOR ENTIRE TEST	16:38	*	N/A	NO PHYSICAL CHANGE
69234	NASA	3	2.14	CARRIED CURRENT FOR 1:22	21:48	146.5	1:12	CASE SWELLED AND HEAT STAINED
69239	NASA	3	2.09	CARRIED CURRENT FOR 0:56	16:29	119.0	0:57	CASE SWELLED AND HEAT STAINED
69245	NASA	3	2.45	CARRIED CURRENT FOR 9:13	16:38	145.0	0:23	CASE SWELLED AND HEAT STAINED
						* NO SIGNIFICANT TEMPERATURE INCREASE		

TEST REQUEST: E•ITR92-019

PERFORMED BY: L.P., S.B.

0NE AMPERE FORCE OVERDISCHARGE

CHEMISTRY: VARIOUS

COMMERCIAL
MEDICAL
* OTHER (R&D EXP.)

SERIAL NUMBER	MODEL	GROUP #	OCV BEFORE TEST	COMMENT	TIME IN VOLTAGE REVERSAL (HR:MIN)	PEAK TEMP. (°C)	TIME TO PEAK TEMP. (HR:MIN)	RESULTS
68991	UNIV.	4	0.12	CARRIED 1A FOR ENTIRE TEST	21:36	*	N/A	NO PHYSICAL CHANGE
68998	UNIV.	4	0.01	COULD NOT CARRY CURRENT	76:42	*	N/A	NO PHYSICAL CHANGE
69005	UNIV.	4	0.25	COULD NOT CARRY CURRENT	18:12	*	N/A	NO PHYSICAL CHANGE
69021	UNIV.	5	3.60	CARRIED 1A FOR ENTIRE TEST	21:34	28.5	0:31	NO PHYSICAL CHANGE
69028	UNIV.	5	3.42	CARRIED CURRENT FOR 8:24	76:37	102.0	8:24	CASE SWELLED AND HEAT STAINED
69032	UNIV.	5	3.46	CARRIED CURRENT FOR 7:54	18:13	132.0	7:54	CASE SWELLED AND CELL VENTED
69053	UNIV.	6	2.31	CARRIED CURRENT FOR ~0:02	21:19	46.5	0:03	CASE SWELLED AND HEAT STAINED
69065	UNIV.	6	3.18	CARRIED CURRENT FOR ~0:04	18:56	138.0	0:04	SWELLING, HEAT STAIN, AND VENT
						* NO SIGNIFICANT TEMPERATURE INCREASE		

TEST REQUEST: E•ITR92-019

PERFORMED BY: L.P., S.B.

0NE AMPERE FORCE OVERDISCHARGE

CHEMISTRY: VARIOUS

COMMERCIAL
MEDICAL
* OTHER (R&D EXP.)

SERIAL NUMBER	MODEL	GROUP #	OCV BEFORE TEST	COMMENT	TIME IN VOLTAGE REVERSAL (HR:MIN)	PEAK TEMP. (°C)	TIME TO PEAK TEMP. (HR:MIN)	RESULTS
68814	JPL	7	0.00	CARRIED 1A FOR ENTIRE TEST	21:59	41.0	1:00	NO PHYSICAL CHANGE
68819	JPL	7	0.00	COULD NOT CARRY CURRENT	76:55	*	N/A	NO PHYSICAL CHANGE
68825	JPL	7	0.01	COULD NOT CARRY CURRENT	18:11	*	N/A	NO PHYSICAL CHANGE
68841	JPL	8	0.03	CARRIED 1A FOR ENTIRE TEST	17:11	38.5	1:01	NO PHYSICAL CHANGE
68848	JPL	8	0.05	CARRIED 1A FOR ENTIRE TEST	20:32	*	0:45	NO PHYSICAL CHANGE
68855	JPL	8	0.02	COULD NOT CARRY CURRENT	67:03	*	N/A	NO PHYSICAL CHANGE
68872	JPL	9	0.02	CARRIED CURRENT FOR 16:02	17:10	146.5	16:11	SWELLING AND LEAK @ GLASS
68878	JPL	9	0.01	CARRIED 1A FOR ENTIRE TEST	20:31	100.0	20:31	CASE SWELLED
68886	JPL	9	0.01	COULD NOT CARRY CURRENT	67:00	*	N/A	NO PHYSICAL CHANGE
						* NO SIGNIFICANT TEMPERATURE INCREASE		

TEST REQUEST: E•ITR92-019 | 0NE AMPERE FORCE OVERDISCHARGE

PERFORMED BY: L.P., S.B. | CHEMISTRY: VARIOUS

COMMERCIAL
MEDICAL
* OTHER (R&D EXP.)

SERIAL NUMBER	MODEL	GROUP #	OCV BEFORE TEST	COMMENT	TIME IN VOLTAGE REVERSAL (HR:MIN)	PEAK TEMP. (°C)	TIME TO PEAK TEMP. (HR:MIN)	RESULTS
69282	NASA	10	3.46	CARRIED 1A FOR ENTIRE TEST	17:14	45.0	0:07	NO PHYSICAL CHANGE
69266	NASA	10	2.93	CARRIED 1A FOR ENTIRE TEST	20:49	33.5	0:12	NO PHYSICAL CHANGE
69269	NASA	10	2.97	CARRIED 1A FOR ENTIRE TEST	66:52	34.5	0:10	NO PHYSICAL CHANGE
69291	NASA	11	3.66	CARRIED 1A FOR ENTIRE TEST	19:06	36.5	0:15	NO PHYSICAL CHANGE
69297	NASA	11	3.66	CARRIED 1A FOR ENTIRE TEST	16:51	39.0	0:24	NO PHYSICAL CHANGE
69305	NASA	11	3.66	CARRIED 1A FOR ENTIRE TEST	21:43	44.0	0:21	NO PHYSICAL CHANGE
69321	NASA	12	0.03	COULD NOT CARRY CURRENT	19:05	*	N/A	NO PHYSICAL CHANGE
69324	NASA	12	1.05	CARRIED CURRENT FOR 2:48	16:48	161.0	3:01	CASE SWELLED AND HEAT STAINED
69335	NASA	12	2.94	CARRIED CURRENT FOR 2:42	21:43	169.5	3:00	CASE SWELLED AND HEAT STAINED
						* NO SIGNIFICANT TEMPERATURE INCREASE		

TEST REQUEST: E•ITR92-019 ONE AMPERE FORCE OVERDISCHARGE

PERFORMED BY: L.P., S.B. CHEMISTRY: VARIOUS

COMMERCIAL
MEDICAL
* OTHER (R&D EXP.)

SERIAL NUMBER	MODEL	GROUP #	OCV BEFORE TEST	COMMENT	TIME IN VOLTAGE REVERSAL (HR:MIN)	PEAK TEMP. (°C)	TIME TO PEAK TEMP. (HR:MIN)	RESULTS
69083	UNIV.	13	0.01	CARRIED CURRENT FOR 13:03	18:56	178.0	13:06	CASE SWELLED AND HEAT STAINED
69090	UNIV.	13	0.01	CARRIED 1A FOR ENTIRE TEST	16:43	*	N/A	NO PHYSICAL CHANGE
69096	UNIV.	13	0.00	CARRIED 1A FOR ENTIRE TEST	17:42	159.0	8:41	CASE SWELLED AND HEAT STAINED
69115	UNIV.	14	2.82	CARRIED CURRENT FOR 7:00	18:57	169.5	6:54	CASE SWELLED AND HEAT STAINED
69120	UNIV.	14	2.81	CARRIED CURRENT FOR 1:08	21:50	81.0	0:30	CASE HEAT STAINED
69123	UNIV.	14	2.81	CARRIED CURRENT FOR 4:40	21:54	152.0	4:37	CASE SWELLED AND HEAT STAINED
69142	UNIV.	15	2.98	COULD NOT CARRY CURRENT	73:30	**	N/A	NO PHYSICAL CHANGE
69148	UNIV.	15	2.97	CARRIED 1A FOR ENTIRE TEST	18:33	33.0	0:22	NO PHYSICAL CHANGE
69155	UNIV.	15	2.98	CARRIED CURRENT FOR 3:08	17:48	146.5	1:13	CASE SWELLED AND HEAT STAINED
						* THERMOCOUPLE MALFUNCTION		
						** NO SIGNIFICANT TEMPERATURE INCREASE		

TEST REQUEST: E•ITR92-019 0NE AMPERE FORCE OVERDISCHARGE

PERFORMED BY: L.P., S.B. CHEMISTRY: VARIOUS

COMMERCIAL
MEDICAL
* OTHER (R&D EXP.)

SERIAL NUMBER	MODEL	GROUP #	OCV BEFORE TEST	COMMENT	TIME IN VOLTAGE REVERSAL (HR:MIN)	PEAK TEMP. (°C)	TIME TO PEAK TEMP. (HR:MIN)	RESULTS
68905	JPL	16	0.00	CARRIED 1A FOR ENTIRE TEST	73:27	36.5	1:22	NO PHYSICAL CHANGE
68910	JPL	16	0.00	CARRIED 1A FOR ENTIRE TEST	18:33	37.5	4:58	NO PHYSICAL CHANGE
68917	JPL	16	0.00	CARRIED 1A FOR ENTIRE TEST	17:48	37.0	4:54	NO PHYSICAL CHANGE
68937	JPL	17	0.02	COULD NOT CARRY CURRENT	19:10	*	N/A	NO PHYSICAL CHANGE
68945	JPL	17	0.00	CARRIED 1A FOR ENTIRE TEST	19:03	37.0	2:40	NO PHYSICAL CHANGE
68934	JPL	17	0.01	CARRIED 1A FOR ENTIRE TEST	16:15	35.0	1:18	NO PHYSICAL CHANGE
68965	JPL	18	0.01	COULD NOT CARRY CURRENT	18:56	*	N/A	NO PHYSICAL CHANGE
68972	JPL	18	0.03	COULD NOT CARRY CURRENT	16:15	*	N/A	NO PHYSICAL CHANGE
68975	JPL	18	0.02	COULD NOT CARRY CURRENT	16:00	*	N/A	NO PHYSICAL CHANGE
						* NO SIGNIFICANT TEMPERATURE INCREASE		

APPENDIX K

ANOVA REPORT FOR 1A FOD WITHOUT BYPASS DIODES

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
Test 5A: 1A FOD without diodes. Output is scale of 1-6 . (Smaller is better)

Procedure:
OUTPUTS ARE CAPACITY, SHELF-LIFE, START UP, SAFETY AND MICROCAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	1	1	1
Experiment # 2 :	1	1	1
Experiment # 3 :	3	3	3
Experiment # 4 :	1	1	1
Experiment # 5 :	1	3	5
Experiment # 6 :	3	5	5
Experiment # 7 :	1	1	1
Experiment # 8 :	1	1	1
Experiment # 9 :	4	3	1
Experiment # 10 :	1	1	1
Experiment # 11 :	1	1	1
Experiment # 12 :	1	3	3
Experiment # 13 :	3	1	3
Experiment # 14 :			

```
                  3              2               3
.............................................................................................................
Experiment # 15 :
                  1              1               3
.............................................................................................................
Experiment # 16 :
                  1              1               1
.............................................................................................................
Experiment # 17 :
                  1              1               1
.............................................................................................................
Experiment # 18 :
                  1              1               1
.............................................................................................................
```

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	2.7	2.7	3.15	1.8	2.35	%
B	2	14.8	7.4	8.72	13.1	16.92	%***
C	2	15.4	7.7	9.11	13.7	17.78	%***
D	2	5.4	2.7	3.21	3.7	4.85	%*
e	46	39	.8		44.9	58.11	%
Total	53	77.3				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY

Number of experiments = 54 Correction Factor = 170.7

Sum (experiment values) = 96 Sum of sqs (experiment values) = 77.3

				RESPONSE TABLE	
Factor:	A	B	C	D	-
LEVEL 1	54	28	22	25	-
LEVEL 2	42	45	29	32	-
LEVEL 3	-	23	45	39	-
Factor:	-	-	-		
LEVEL 1	-	-	-		
LEVEL 2	-	-	-		
LEVEL 3	-	-	-		

				RESPONSE TABLE (AVERAGES)	
Factor:	A	B	C	D	-
LEVEL 1	2	1.6	1.2	1.4	-
LEVEL 2	1.6	2.5	1.6	1.8	-
LEVEL 3	-	1.3	2.5	2.2	-
Factor:	-	-	-		
LEVEL 1	-	-	-		
LEVEL 2	-	-	-		
LEVEL 3	-	-	-		

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY

Quality Characteristic: ... the smaller the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	1.6
CELL DESIGN	JPL D	3	1.3
DEPOLARIZER TYPE	BCX	1	1.2
ELECTTROLYTE CONC.	0.6M	1	1.4

Total Contribution from significant factors = 5.5

Average Total for all results = 1.8

Estimate of average result (optimum) = .2

APPENDIX L

ANOVA REPORT FOR 3A FOD WITHOUT BYPASS DIODES

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
Test 5B: 3A FOD without diodes. Output is scale of 1-6 (smaller is better)

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS [3 Trial(s) per Experiment]

	Trial # 1	Trial # 2	Trial # 3
Experiment # 1 :	1	1	1
Experiment # 2 :	1	1	1
Experiment # 3 :	2	5	5
Experiment # 4 :	1	1	1
Experiment # 5 :	1	1	1
Experiment # 6 :	5	5	3
Experiment # 7 :	1	1	1
Experiment # 8 :	1	1	1
Experiment # 9 :	1	1	1
Experiment # 10 :	3	3	3
Experiment # 11 :	6	5	4
Experiment # 12 :	5	6	5
Experiment # 13 :	3	3	3
Experiment # 14 :	3	3	3

ORIGINAL PAGE IS
OF POOR QUALITY

Experiment # 15 :

1	1	1

....

Experiment # 16 :

1	1	1

....

Experiment # 17 :

1	1	1

....

Experiment # 18 :

1	3	1

....

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)
A	1	12.5	12.5	9.13	11.1	7.95 %***
B	2	40.1	20.1	14.64	37.4	26.69 %***
C	2	14.4	7.2	5.24	11.6	8.3 %**
D	2	10	5	3.66	7.3	5.2 %*
e	46	63.1	1.4		72.7	51.85 %
Total	53	140.1				100.00 %

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 54
Sum (experiment values) = 118
Correction Factor = 257.9
Sum of sqs (experiment values) = 140.1

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	46	58	30	30	-
LEVEL 2	72	40	36	39	-
LEVEL 3	-	20	52	49	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	1.7	3.2	1.7	1.7	-
LEVEL 2	2.7	2.2	2	2.2	-
LEVEL 3	-	1.1	2.9	2.7	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY

Quality Characteristic: ... the smaller the better ...

Significant Factors	Optimum Settings	Level *	Contribution
ELECTROLYTE TYPE	LAC	1	1.7
CELL DESIGN	JPL D	3	1.1
DEPOLARIZER TYPE	BCX	1	1.7
ELECTTROLYTE CONC.	0.6M	1	1.7

Total Contribution from significant factors =
6.2

Average Total for all results = 2.2

Estimate of average result (optimum) =
-.4

APPENDIX M

RELIABILITY REPORT #92-080
3A FOD WITHOUT BYPASS DIODES

WILSON GREATBATCH LTD.

RELIABILITY TEST RESULTS

MODEL: D (VARIOUS CHEMISTRIES)	DATE: 06 JUNE 1992	REPORT NO: 92-080
TEST: CONSTANT CURRENT FORCE OVERDISCHARGE W/O DIODES		

ORIGINATOR: P. Size (Refer E•ITR92-048)

PURPOSE: The purpose of this test is to satisfy the requirements as stated in the NASA Contract NAS9-18395 para. 9.2.2.

PARAMETERS: Fifty-four cells of various constructions and chemistries were submitted for test. The cells were three ampere constant current force overdischarged at room temperature for a minimum of five hours in voltage reversal with a maximum preset voltage push of 38 volts. The cells were not protected with by-pass diodes. Voltage, current, and skin temperature were monitored and recorded. **NOTE:** These cells were previously tested as stated above but were equipped with protective shunt diodes. This information is documented on RTR92-044.

TEST RESULTS: Refer attachments (Tables 1-6)

SUBMITTED BY: Thomas R. Umphrey	DATE: 06 June 92
APPROVED BY: [signature]	DATE: 08 June 92
DISTRIBUTION: P. SIZE	PAGE: 1 OF 7

FORM NO. 7044/0783 "REV A"

TEST REQUEST: E•ITR92-048

PERFORMED BY: L.P., S.B.

THREE AMPERE FORCE OVERDISCHARGE
W/O DIODES
CHEMISTRY: VARIOUS

COMMERCIAL
MEDICAL
* OTHER (R&D EXP.)

SERIAL NUMBER	MODEL	GROUP #	OCV BEFORE TEST	COMMENT	TIME IN VOLTAGE REVERSAL (HR:MIN)	PEAK TEMP. (°C)	TIME TO PEAK TEMP. (HR:MIN)	RESULTS
68811	JPL	7	0.01	COULD NOT CARRY CURRENT	17:03	*	N/A	NO PHYSICAL CHANGE
68818	JPL	7	0.01	COULD NOT CARRY CURRENT	5:21	*	N/A	NO PHYSICAL CHANGE
68822	JPL	7	0.01	COULD NOT CARRY CURRENT	17:16	*	N/A	NO PHYSICAL CHANGE
68842	JPL	8	0.01	COULD NOT CARRY CURRENT	17:02	*	N/A	NO PHYSICAL CHANGE
68845	JPL	8	0.01	COULD NOT CARRY CURRENT	5:20	*	N/A	NO PHYSICAL CHANGE
68853	JPL	8	0.02	COULD NOT CARRY CURRENT	17:20	*	N/A	NO PHYSICAL CHANGE
68875	JPL	9	0.01	COULD NOT CARRY CURRENT	6:09	*	N/A	NO PHYSICAL CHANGE
68879	JPL	9	0.01	COULD NOT CARRY CURRENT	5:19	*	N/A	NO PHYSICAL CHANGE
68885	JPL	9	0.01	COULD NOT CARRY CURRENT	5:13	*	N/A	NO PHYSICAL CHANGE
						* NO SIGNIFICANT TEMPERATURE RISE		

TEST REQUEST: E•ITR92-048

PERFORMED BY: L.P., S.B.

THREE AMPERE FORCE OVERDISCHARGE
W/O DIODES
CHEMISTRY: VARIOUS

COMMERCIAL
MEDICAL
* OTHER (R&D EXP.)

SERIAL NUMBER	MODEL	GROUP #	OCV BEFORE TEST	COMMENT	TIME IN VOLTAGE REVERSAL (HR:MIN)	PEAK TEMP. (°C)	TIME TO PEAK TEMP. (HR:MIN)	RESULTS
68901	JPL	16	0.01	CARRIED CURRENT	5:40	51.5	1:25	NO PHYSICAL CHANGE
68908	JPL	16	0.01	COULD NOT CARRY CURRENT	6:03	*	N/A	NO PHYSICAL CHANGE
68914	JPL	16	0.00	CARRIED CURRENT	6:03	43.0	1:06	NO PHYSICAL CHANGE
								NO PHYSICAL CHANGE
68931	JPL	17	0.02	COULD NOT CARRY CURRENT	5:01	*	N/A	NO PHYSICAL CHANGE
68940	JPL	17	0.03	COULD NOT CARRY CURRENT	19:14	*	N/A	NO PHYSICAL CHANGE
68943	JPL	17	0.02	COULD NOT CARRY CURRENT	5:03	*	N/A	NO PHYSICAL CHANGE
68961	JPL	18	0.02	CARRIED CURRENT	5:00	54.0	0:47	NO PHYSICAL CHANGE
68968	JPL	18	0.02	CARRIED CURRENT	19:11	87.0	19:09	CASE SWELLED
68974	JPL	18	0.01	CARRIED 3A FOR 5:00	21:09	53.5	0:57	NO PHYSICAL CHANGE
						* NO SIGNIFICANT TEMPERATURE INCREASE		

TEST REQUEST: E•ITR92-048

PERFORMED BY: L.P., S.B.

THREE AMPERE FORCE OVERDISCHARGE
W/O DIODES
CHEMISTRY: VARIOUS

COMMERCIAL
MEDICAL
• OTHER (R&D EXP.)

SERIAL NUMBER	MODEL	GROUP #	OCV BEFORE TEST	COMMENT	TIME IN VOLTAGE REVERSAL (HR:MIN)	PEAK TEMP. (°C)	TIME TO PEAK TEMP. (HR:MIN)	RESULTS
68993	UNIV.	4	0.00	COULD NOT CARRY CURRENT	<1 SEC	*	N/A	NO PHYSICAL CHANGE
68995	UNIV.	4	3.59	CARRIED CURRENT	16:13	42.0	0:18	NO PHYSICAL CHANGE
69002	UNIV.	4	2.40	CARRIED CURRENT	18:39	39.5	0:27	NO PHYSICAL CHANGE
69024	UNIV.	5	3.62	COULD NOT CARRY CURRENT	5:15	*	N/A	NO PHYSICAL CHANGE
69030	UNIV.	5	3.62	COULD NOT CARRY CURRENT	16:13	*	N/A	NO PHYSICAL CHANGE
69035	UNIV.	5	3.61	COULD NOT CARRY CURRENT	18:52	*	N/A	NO PHYSICAL CHANGE
69051	UNIV.	6	3.19	CARRIED CURRENT	<1 SEC	81.0	<1 SEC	CELL VENTED
69056	UNIV.	6	2.47	CARRIED CURRENT	16:20	100.5	16:11	CELL VENTED
69061	UNIV.	6	2.26	COULD NOT CARRY CURRENT	18:52	112.0	0:03	CASE SWELLED
					* NO SIGNIFICANT TEMPERATURE INCREASE			

TEST REQUEST: E•ITR92-048

PERFORMED BY: L.P., S.B.

THREE AMPERE FORCE OVERDISCHARGE
W/O DIODES
CHEMISTRY: VARIOUS

COMMERCIAL
MEDICAL
• OTHER (R&D EXP.)

SERIAL NUMBER	MODEL	GROUP #	OCV BEFORE TEST	COMMENT	TIME IN VOLTAGE REVERSAL (HR:MIN)	PEAK TEMP. (°C)	TIME TO PEAK TEMP. (HR:MIN)	RESULTS
69085	UNIV.	13	3.65	CARRIED CURRENT	3:10	226.0	3:00	CASE HEAT STAINED AND SWOLLEN
69089	UNIV.	13	3.63	CARRIED CURRENT	2:45	219.5	1:47	CASE HEAT STAINED AND SWOLLEN
69093	UNIV.	13	3.61	CARRIED CURRENT	5:41	174.0	4:10	CASE HEAT STAINED AND SWOLLEN
69111	UNIV.	14	2.72	CARRIED CURRENT	5:27	223.5	0:14	CASE HEAT STAINED AND SWOLLEN
69116	UNIV.	14	2.73	CARRIED 3A FOR 0:58	18:54	167.0	0:41	CASE HEAT STAINED AND SWOLLEN
69121	UNIV.	14	2.72	CARRIED 3A FOR 3:08	17:43	236.5	1:48	CASE HEAT STAINED AND SWOLLEN
69141	UNIV.	15	3.87	CARRIED CURRENT	5:38	66.5	0:18	NO PHYSICAL CHANGE
69145	UNIV.	15	2.96	CARRIED CURRENT	19:29	31.0	0:16	NO PHYSICAL CHANGE
69151	UNIV.	15	2.97	CARRIED 3A FOR 9:54	16:06	57.0	9:56	NO PHYSICAL CHANGE

TEST REQUEST: E•ITR92-048

PERFORMED BY: L.P., S.B.

THREE AMPERE FORCE OVERDISCHARGE
W/O DIODES
CHEMISTRY: VARIOUS

COMMERCIAL
MEDICAL
* OTHER (R&D EXP.)

SERIAL NUMBER	MODEL	GROUP #	OCV BEFORE TEST	COMMENT	TIME IN VOLTAGE REVERSAL (HR:MIN)	PEAK TEMP. (°C)	TIME TO PEAK TEMP. (HR:MIN)	RESULTS
69192	NASA	1	3.65	CARRIED CURRENT	5:09	44.0	2:55	NO PHYSICAL CHANGE
69180	NASA	1	3.64	COULD NOT CARRY CURRENT	15:51	*	N/A	NO PHYSICAL CHANGE
69183	NASA	1	3.63	CARRIED CURRENT	15:01	39.0	0:04	NO PHYSICAL CHANGE
69201	NASA	2	3.59	CARRIED CURRENT	5:08	46.0	0:57	NO PHYSICAL CHANGE
69206	NASA	2	3.65	CARRIED CURRENT	15:53	41.0	0:48	NO PHYSICAL CHANGE
69212	NASA	2	3.59	CARRIED CURRENT	6:07	52.5	0:39	NO PHYSICAL CHANGE
69231	NASA	3	3.18	CARRIED CURRENT	6:05	80.5	6:05	HEAT STAIN ON SIDE OF CASE
69236	NASA	3	3.19	CARRIED CURRENT FOR 1:57	18:19	>250	<1 SEC	CELL VENTED
69242	NASA	3	2.28	CARRIED CURRENT FOR 1:37	18:18	145.0	1:38	CELL VENTED
						* NO SIGNIFICANT TEMPERATURE INCREASE		

TEST REQUEST: E•ITR92-048

PERFORMED BY: L.P., S.B.

THREE AMPERE FORCE OVERDISCHARGE
W/O DIODES
CHEMISTRY: VARIOUS

COMMERCIAL
MEDICAL
• OTHER (R&D EXP.)

SERIAL NUMBER	MODEL	GROUP #	OCV BEFORE TEST	COMMENT	TIME IN VOLTAGE REVERSAL (HR:MIN)	PEAK TEMP. (°C)	TIME TO PEAK TEMP. (HR:MIN)	RESULTS
69262	NASA	10	3.59	CARRIED CURRENT	6:05	211.5	2:30	CASE HEAT STAINED AND SWOLLEN
69265	NASA	10	3.64	CARRIED CURRENT	5:08	162.0	4:48	CASE HEAT STAINED AND SWOLLEN
69275	NASA	10	3.63	CARRIED CURRENT	5:13	151.0	3:39	CASE SWELLED
69293	NASA	11	3.67	CARRIED CURRENT	<30 SEC	43.0	<30 SEC	RUPTURE
69326	NASA	11	2.79	CARRIED CURRENT	0:14	182.0	O:14	VENT THROUGH GLASS SEAL
69303	NASA	11	3.67	CARRIED CURRENT	4:23	151.5	4:11	CASE HEAT STAINED AND SWOLLEN
69323	NASA	12	2.94	CARRIED CURRENT	0:16	166.0	0:15	VENT THROUGH GLASS SEAL
69300	NASA	12	3.67	CARRIED CURRENT	1:21	112.5	1:20	RUPTURE
69331	NASA	12	2.93	CARRIED CURRENT	0:11	152.5	0:10	VENT THROUGH GLASS SEAL

APPENDIX N

ANOVA REPORTS FOR 2Ω SHORT CIRCUIT DATA

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
DETERMINE ENERGY OBTAINED UPON 2Ω "SHORT CIRCUIT"

Procedure:
OUTPUTS ARE ENERGY IN JOULES

Comment:
JPL AND NASA D CELLS TO BE MODIFIED FOR MACHINE WINDING.

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.

3 DESIGN MATRICES BUILT FOR EACH TEST CONDITION.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS [1 Trial(s) per Experiment]

Trial # 1

Experiment # 1 :
70692

Experiment # 2 :
74073

Experiment # 3 :
173873

Experiment # 4 :
81334

Experiment # 5 :
104303

Experiment # 6 :
157323

Experiment # 7 :
102739

Experiment # 8 :
87815

Experiment # 9 :
141308

Experiment # 10 :
150195

Experiment # 11 :
91031

Experiment # 12 :

148875

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Experiment # 13 :

157546

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Experiment # 14 :

147549

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Experiment # 15 :

174133

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Experiment # 16 :

107103

....

Experiment # 17 :

139991

....

Experiment # 18 :

130042

....

ANALYSIS OF VARIATION							
Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	3556196112.5					
			3556196112.5	6.13	2975894455.1	14.62	%*
B	2	1426817710.1					
			713408855.1	1.23	266214395.3	1.31	%
C	2	8053853538.8					
			4026926769.4	6.94	6893250224	33.86	%*
D	2	1520956360.1					
			760478180.1	1.31	360353045.3	1.77	%
e	10	5803016574.1					
			580301657.4		9865128176	48.45	%
Total	17	20360840295.6				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 18 Correction Factor = 278736889201.4
Sum (experiment values) = 2239925 Sum of sqs (experiment values) = 20360840295.6

R E S P O N S E   T A B L E

Factor:	A	B	C	D	-
LEVEL 1	993460	708739	669609	698489	-
LEVEL 2	1246465	822188	644762	717578	-
LEVEL 3	-	708998	925554	823858	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

R E S P O N S E   T A B L E   (A V E R A G E S)

Factor:	A	B	C	D	-
LEVEL 1	110384.4	118123.2	111601.5	116414.8	-
LEVEL 2	138496.1	137031.3	107460.3	119596.3	-
LEVEL 3	-	118166.3	154259	137309.7	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

M A I N   E F F E C T S   A N A L Y S I S

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the smaller the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LAC	1	110384.4
CELL DESIGN	NASA149 D	1	118123.2
DEPOLARIZER TYPE	TC	2	107460.3
ELECTTROLYTE CONC.	0.6M	1	116414.8

Total Contribution from significant factors =
452382.7
Average Total for all results = 124440.3
Estimate of average result (optimum) =
79061.9

DESCRIPTION OF EXPERIMENT

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
Compare the effects of the tested factors on capacity under 2Ω "smart short".

Procedure:
OUTPUTS ARE CAPACITY

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS [1 Trial(s) per Experiment]

Trial # 1

Experiment # 1 :
4.26

Experiment # 2 :
4.63

Experiment # 3 :
15.68

Experiment # 4 :
4.9

Experiment # 5 :
7.1

Experiment # 6 :
14.29

Experiment # 7 :
7.95

Experiment # 8 :
7.03

Experiment # 9 :
9.8

Experiment # 10 :
10.69

Experiment # 11 :
6.08

Experiment # 12 :
13.4

Experiment # 13 :
12.99

....

Experiment # 14 :
11.64

....

Experiment # 15 :
13.12

....

Experiment # 16 :
7.09

....

Experiment # 17 :
10.73

....

Experiment # 18 :
9.92

....

					ANALYSIS OF VARIATION	
Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)
A	1	22.27	22.27	3.62	16.11	7.55 %
B	2	12.45	6.23	1.01	.14	.07 %
C	2	91.34	45.67	7.42	79.03	37.02 %*
D	2	25.92	12.96	2.11	13.61	6.37 %
e	10	61.53	6.15		104.61	49 %
Total	17	213.5				100.00 %

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 18   Correction Factor = 1630.21
Sum (experiment values) = 171.3   Sum of sqs (experiment values) = 213.5

R E S P O N S E T A B L E

Factor:	A	B	C	D	-
LEVEL 1	75.64	54.74	47.88	48.89	-
LEVEL 2	95.66	64.04	47.21	55.99	-
LEVEL 3	-	52.52	76.21	66.42	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

R E S P O N S E T A B L E (A V E R A G E S)

Factor:	A	B	C	D	-
LEVEL 1	8.4	9.12	7.98	8.15	-
LEVEL 2	10.63	10.67	7.87	9.33	-
LEVEL 3	-	8.75	12.7	11.07	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

M A I N E F F E C T S A N A L Y S I S

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	10.63
CELL DESIGN	UNIV D	2	10.67
DEPOLARIZER TYPE	CSC	3	12.7
ELECCTTROLYTE CONC.	1.8M	3	11.07

Total Contribution from significant factors =
45.07
Average Total for all results = 9.52
Estimate of average result (optimum) =
16.52

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY
Goal/Objective:
DETERMINE EFFECTS OF VARIOUS PARAMETERS ON HEAT OUTPUT UNDER 2Ω LOADS.
Procedure:
OUTPUT IS J/AHR (TO 2.0V)

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.
Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [1 Trial(s) per Experiment]

Trial # 1

Experiment # 1 :
24641

Experiment # 2 :
16468

Experiment # 3 :
10929

Experiment # 4 :
17200

Experiment # 5 :
16427

Experiment # 6 :
10971

Experiment # 7 :
14354

Experiment # 8 :
16605

Experiment # 9 :
11332

Experiment # 10 :
12370

Experiment # 11 :
16031

Experiment # 12 :
13357

Experiment # 13 :
10948

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Experiment # 14 :
12492
....
Experiment # 15 :
13249
....
Experiment # 16 :
13253
....
Experiment # 17 :
12739
....
Experiment # 18 :
12294
....

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)
A	1	27365202	27365202	3.72	20006851.4	10.43 %
B	2	18428952.3	9214476.2	1.25	3712251.1	1.94 %
C	2	43158604	21579302	2.93	28441902.7	14.83 %
D	2	29213861.3	14606930.7	1.99	14497160.1	7.56 %
e	10	73583506.3	7358350.6		125091960.8	65.24 %
Total	17	191750126				100.00 %

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 18 Correction Factor = 3631224200
Sum (experiment values) = 255660 Sum of sqs (experiment values) = 191750126

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	138927	93796	92766	95192	-
LEVEL 2	116733	81287	90762	83848	-
LEVEL 3	-	80577	72132	76620	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	15436.3	15632.7	15461	15865.3	-
LEVEL 2	12970.3	13547.8	15127	13974.7	-
LEVEL 3	-	13429.5	12022	12770	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the smaller the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	12970.3
CELL DESIGN	JPL D	3	13429.5
DEPOLARIZER TYPE	CSC	3	12022
ELECTTROLYTE CONC.	1.8M	3	12770

Total Contribution from significant factors =
51191.8
Average Total for all results = 14203.3
Estimate of average result (optimum) =
8581.8

APPENDIX O

ANOVA REPORTS FOR 0.7Ω SHORT CIRCUIT DATA

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
COMPARE THE EFFECTS OF TESTED FACTORS ON HEAT OUTPUT UNDER 0.700Ω SMART SHORT.

Procedure:
OUTPUTS ARE ENERGY (J)

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [1 Trial(s) per Experiment]

Trial # 1

Experiment # 1 :
56675

Experiment # 2 :
69823

Experiment # 3 :
164051

Experiment # 4 :
56760

Experiment # 5 :
83119

Experiment # 6 :
158528

Experiment # 7 :
101198

Experiment # 8 :
118226

Experiment # 9 :
112182

Experiment # 10 :
132360

Experiment # 11 :
66046

Experiment # 12 :
152804

Experiment # 13 :
129848

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Experiment # 14 :

144659

....

Experiment # 15 :

148394

....

Experiment # 16 :

88001

....

Experiment # 17 :

131086

....

Experiment # 18 :

121221

....

A N A L Y S I S   O F   V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	2087807580.5	2087807580.5	3.39	1472518440	6.8	%
B	2	537618592.3	268809296.2	.44	0	0	%
C	2	8190036043	4095018021.5	6.66	6959457761.9	32.13	%*
D	2	4692801409.3	2346400704.7	3.81	3462223128.3	15.98	%
e	10	6152891405.3	615289140.5		9766955700.3	45.09	%
Total	17	21661155030.5				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 18 Correction Factor = 230063759464.5
Sum (experiment values) = 2034981 Sum of sqs (experiment values) = 21661155030.5

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	920562	641759	564842	571143	-
LEVEL 2	1114419	721308	612959	658013	-
LEVEL 3	-	671914	857180	805825	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	102284.7	106959.8	94140.3	95190.5	-
LEVEL 2	123824.3	120218	102159.8	109668.8	-
LEVEL 3	-	111985.7	142863.3	134304.2	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the smaller the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LAC	1	102284.7
CELL DESIGN	NASA149 D	1	106959.8
DEPOLARIZER TYPE	BCX	1	94140.3
ELECTTROLYTE CONC.	0.6M	1	95190.5

Total Contribution from significant factors = 398575.3
Average Total for all results = 113054.5
Estimate of average result (optimum) = 59411.8

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY
Goal/Objective:
COMPARE THE EFFECTS OF TESTED FACTORS ON CAPACITY OF D CELLS UNDER 0.700Ω SMART SHORT
Procedure:
OUTPUTS ARE CAPACITY

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.
Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [1 Trial(s) per Experiment]

Trial # 1

Experiment # 1 :
2.3

Experiment # 2 :
4.24

Experiment # 3 :
15.01

Experiment # 4 :
3.3

Experiment # 5 :
5.06

Experiment # 6 :
14.45

Experiment # 7 :
7.05

Experiment # 8 :
7.12

Experiment # 9 :
9.9

Experiment # 10 :
10.7

Experiment # 11 :
4.12

Experiment # 12 :
11.44

Experiment # 13 :
11.86

....
Experiment # 14 :
11.58

....
Experiment # 15 :
11.2

....
Experiment # 16 :
6.64

....
Experiment # 17 :
10.29

....
Experiment # 18 :
9.86

....

A N A L Y S I S   O F   V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	20.61	20.61	2.95	13.63	5.5	%
B	2	8.09	4.05	.58	0	0	%
C	2	98.23	49.12	7.04	84.27	33.99	%*
D	2	51.17	25.59	3.67	37.21	15.01	%
e	10	69.81	6.98		112.81	45.5	%
Total	17	247.92				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 18   Correction Factor = 1354.08
Sum (experiment values) = 156.12   Sum of sqs (experiment values) = 247.92

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	68.43	47.81	41.85	41.11	-
LEVEL 2	87.69	57.45	42.41	49.51	-
LEVEL 3	-	50.86	71.86	65.5	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	7.6	7.97	6.98	6.85	-
LEVEL 2	9.74	9.58	7.07	8.25	-
LEVEL 3	-	8.48	11.98	10.92	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	9.74
CELL DESIGN	UNIV D	2	9.58
DEPOLARIZER TYPE	CSC	3	11.98
ELECTTROLYTE CONC.	1.8M	3	10.92

Total Contribution from significant factors =
42.22
Average Total for all results = 8.67
Estimate of average result (optimum) =
16.2

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
DETERMINE EFFECTS OF VARIOUS PARAMETERS ON HEAT OUTPUT UNDER [illegible]Ω LOADS.

Procedure:
OUTPUT IS J/AHR

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   [1 Trial(s) per Experiment]

	Trial # 1
Experiment # 1 :	16594
Experiment # 2 :	15998
Experiment # 3 :	11089
Experiment # 4 :	16599
Experiment # 5 :	14691
Experiment # 6 :	11009
Experiment # 7 :	12923
Experiment # 8 :	12491
Experiment # 9 :	14419
Experiment # 10 :	14050
Experiment # 11 :	14972
Experiment # 12 :	11110
Experiment # 13 :	12128

....

Experiment # 14 :

12676

....

Experiment # 15 :

13272

....

Experiment # 16 :

15106

....

Experiment # 17 :

13047

....

Experiment # 18 :

13109

....

A N A L Y S I S   O F   V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)
A	1	2235202.7	2235202.7	1.05	104980	.19 %
B	2	1095876	547938	.26	0	0 %
C	2	16062721	8031360.5	3.77	11802275.5	21.66 %
D	2	13795161.3	6897580.7	3.24	9534715.8	17.5 %
e	10	21302227.4	2130222.7		33049217.2	60.65 %
Total	17	54491188.5				100.00 %

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence   ** = 99% Confidence   *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 18   Correction Factor = 3342430560.5
Sum (experiment values) = 245283   Sum of sqs (experiment values) = 54491188.5

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	125813	83813	87400	88903	-
LEVEL 2	119470	80375	83875	79959	-
LEVEL 3	-	81095	74008	76421	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	13979.2	13968.8	14566.7	14817.2	-
LEVEL 2	13274.4	13395.8	13979.2	13326.5	-
LEVEL 3	-	13515.8	12334.7	12736.8	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the smaller the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	13274.4
CELL DESIGN	UNIV D	2	13395.8
DEPOLARIZER TYPE	CSC	3	12334.7
ELECTTROLYTE CONC.	1.8M	3	12736.8

Total Contribution from significant factors =
51741.7
Average Total for all results = 13626.8
Estimate of average result (optimum) =
10861.2

APPENDIX P

ANOVA REPORTS FOR 0.325Ω SHORT CIRCUIT DATA

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY

Goal/Objective:
DETERMINE EFFECTS OF TESTED FACTORS ON HEAT OUTPUT UNDER 0.325Ω SMART SHORT.

Procedure:
OUTPUT IS ENERGY (J)

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   (1 Trial(s) per Experiment)

Trial # 1

Experiment # 1 :
45767

Experiment # 2 :
70044

Experiment # 3 :
165217

Experiment # 4 :
48078

Experiment # 5 :
77640

Experiment # 6 :
156453

Experiment # 7 :
97190

Experiment # 8 :
102281

Experiment # 9 :
113056

Experiment # 10 :
135014

Experiment # 11 :
77346

Experiment # 12 :
146914

Experiment # 13 :
115574

....

Experiment # 14 :
139962

....

Experiment # 15 :
89803

....

Experiment # 16 :
86777

....

Experiment # 17 :
115237

....

Experiment # 18 :
107498

....

A N A L Y S I S   O F   V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)
A	1	1064126844.5	1064126844.5	1.69	435055381.2	2.12 %
B	2	29283570.8	14641785.4	.02	0	0 %
C	2	5793545696.8	2896772848.4	4.6	4535402770.1	22.06 %*
D	2	7378849364.1	3689424682.1	5.86	6120706437.4	29.78 %*
e	10	6290714633.4	629071463.3		9465355520.9	46.05 %
Total	17	20556520109.6				100.00 %

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence   ** = 99% Confidence   *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 18   Correction Factor = 198418711233.4
Sum (experiment values) = 1889851   Sum of sqs (experiment values) = 20556520109.6

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	875726	640302	528400	489287	-
LEVEL 2	1014125	627510	582510	614860	-
LEVEL 3	-	622039	778941	785704	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	97302.9	106717	88066.7	81547.8	-
LEVEL 2	112680.6	104585	97085	102476.7	-
LEVEL 3	-	103673.2	129823.5	130950.7	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the smaller the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LAC	1	97302.9
CELL DESIGN	JPL D	3	103673.2
DEPOLARIZER TYPE	BCX	1	88066.7
ELECTTROLYTE CONC.	0.6M	1	81547.8

Total Contribution from significant factors =
370590.6
Average Total for all results = 104991.7
Estimate of average result (optimum) =
55615.4

D E S C R I P T I O N   O F   E X P E R I M E N T

Title of Experiment:
NASA D CELL COMPARISON STUDY
Goal/Objective:
DETERMINE EFFECTS OF TESTED FACTORS ON CAPACITY OF D CELLS UNDER 0.325Ω SMART SHORT.
Procedure:
OUTPUT IS CAPACITY (Ah)

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.
Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

E X P E R I M E N T   R E S U L T S   (1 Trial(s) per Experiment)

Trial # 1

Experiment # 1 :
2.66

Experiment # 2 :
4.43

Experiment # 3 :
14.58

Experiment # 4 :
2.88

Experiment # 5 :
5.03

Experiment # 6 :
14.22

Experiment # 7 :
7.26

Experiment # 8 :
8.66

Experiment # 9 :
8.38

Experiment # 10 :
10.64

Experiment # 11 :
5.26

Experiment # 12 :
12.97

Experiment # 13 :
8.12

....

Experiment # 14 :
12.41

....

Experiment # 15 :
5.84

....

Experiment # 16 :
6.9

....

Experiment # 17 :
10.32

....

Experiment # 18 :
9.69

....

A N A L Y S I S   O F   V A R I A T I O N

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)
A	1	10.97	10.97	1.68	4.44	1.93 %
B	2	.66	.33	.05	0	0 %
C	2	65.69	32.85	5.03	52.63	22.88 %*
D	2	87.38	43.69	6.69	74.32	32.31 %*
e	10	65.3	6.53		98.61	42.87 %
Total	17	229.99				100.00 %

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence   ** = 99% Confidence   *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 18   Correction Factor = 1254.17
Sum (experiment values) = 150.25   Sum of sqs (experiment values) = 229.99

RESPONSE TABLE

Factor:	A	B	C	D	-
LEVEL 1	68.1	50.54	38.46	35.34	-
LEVEL 2	82.15	48.5	46.11	47.5	-
LEVEL 3	-	51.21	65.68	67.41	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

RESPONSE TABLE (AVERAGES)

Factor:	A	B	C	D	-
LEVEL 1	7.57	8.42	6.41	5.89	-
LEVEL 2	9.13	8.08	7.69	7.92	-
LEVEL 3	-	8.54	10.95	11.24	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

MAIN EFFECTS ANALYSIS

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the bigger the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	9.13
CELL DESIGN	JPL D	3	8.54
DEPOLARIZER TYPE	CSC	3	10.95
ELECTTROLYTE CONC.	1.8M	3	11.24

Total Contribution from significant factors = 39.86
Average Total for all results = 8.35
Estimate of average result (optimum) = 14.82

DESCRIPTION OF EXPERIMENT

Title of Experiment:

NASA D CELL COMPARISON STUDY

Goal/Objective:

DETERMINE EFFECTS OF TESTED FACTORS ON HEAT OUTPUT D CELLS UNDER 0.325Ω SMART SHORT.

Procedure:

OUTPUT IS J/Ah

ALL CELLS UTILIZE H&V SEPARATOR MATERIAL.

Standard Orthogonal Array Model Used: L18-2-1-3-7

Col.	Label	Description of factor	Level 1	Level 2	Level 3	Level 4
1	A	ELECTROLYTE TYPE	LAC	LGC		
2	B	CELL DESIGN	NASA149 D	UNIV D	JPL D	
3	C	DEPOLARIZER TYPE	BCX	TC	CSC	
4	D	ELECTTROLYTE CONC.	0.6M	1.2M	1.8M	
5						
6						
7						
8						

EXPERIMENT RESULTS [1 Trial(s) per Experiment]

Trial # 1

Experiment # 1 :
17206

Experiment # 2 :
15811

Experiment # 3 :
11332

Experiment # 4 :
16694

Experiment # 5 :
15435

Experiment # 6 :
11002

Experiment # 7 :
13387

Experiment # 8 :
11811

Experiment # 9 :
13491

Experiment # 10 :
12689

Experiment # 11 :
14705

Experiment # 12 :
11327

Experiment # 13 :
14233

....

Experiment # 14 :
11278

....

Experiment # 15 :
15377

....

Experiment # 16 :
12576

....

Experiment # 17 :
11166

....

Experiment # 18 :
11094

....

ANALYSIS OF VARIATION

Factor	Df	Sums of Squares	Variance	F-Ratio	Pure Sum of Sqs.	P(%)	
A	1	7636232	7636232	5.46	6238058.7	8.38	%*
B	2	11229536.8	5614768.4	4.02	8433190.1	11.33	%
C	2	14436520.8	7218260.4	5.16	11640174.1	15.64	%*
D	2	27146061.4	13573030.7	9.71	24349714.8	32.71	%***
e	10	13981733.4	1398173.3		23768946.9	31.93	%
Total	17	74430084.4				100.00	%

[Note: Insignificant factors are pooled and indicated by parenthesis.]
* = 95% Confidence ** = 99% Confidence *** = 99.5% Confidence

NASA D CELL COMPARISON STUDY
Number of experiments = 18
Sum (experiment values) = 240614
Correction Factor = 3216394277.6
Sum of sqs (experiment values) = 74430084.4

R E S P O N S E T A B L E

Factor:	A	B	C	D	-
LEVEL 1	126169	83070	86785	88639	-
LEVEL 2	114445	84019	80206	81287	-
LEVEL 3	-	73525	73623	70688	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

R E S P O N S E T A B L E (A V E R A G E S)

Factor:	A	B	C	D	-
LEVEL 1	14018.8	13845	14464.2	14773.2	-
LEVEL 2	12716.1	14003.2	13367.7	13547.8	-
LEVEL 3	-	12254.2	12270.5	11781.3	-

Factor:	-	-	-
LEVEL 1	-	-	-
LEVEL 2	-	-	-
LEVEL 3	-	-	-

M A I N E F F E C T S A N A L Y S I S

NASA D CELL COMPARISON STUDY
Quality Characteristic: ... the smaller the better ...

Significant Factors	Optimum Settings	Level #	Contribution
ELECTROLYTE TYPE	LGC	2	12716.1
CELL DESIGN	JPL D	3	12254.2
DEPOLARIZER TYPE	CSC	3	12270.5
ELECTTROLYTE CONC.	1.8M	3	11781.3

Total Contribution from significant factors =
49022.1

Average Total for all results = 13367.4
Estimate of average result (optimum) =
8919.8